ECONOMIC GEOLOGY

WITH WHICH IS INCORPORATED

THE AMERICAN GEOLOGIST

VOL. VII JANUARY, 1912 No. 1

BRUN'S NEW DATA ON VOLCANISM.

ALEXANDER N. WINCHELL.

Albert Brun in his recent publication entitled, "Recherches sur l'Exhalaison Volcanique," has presented a large quantity of new data of much importance to geologists and petrologists. It is the purpose of the present writer to make this new information more accessible to American geologists through presentation here, and more easily apprehended as a whole through tabulation.

The following measurements of certain temperatures of lavas and their calorific capacity have been made by various methods carefully described, including the use of Sëger cones for approximations, and the use of thermo-elements or platinum blocks with calorimeters for precise determinations.

The fusing point (F. P.) of lava is defined as the temperature at which the "ropy" structure may be produced by a pressure not greater than two grams per square millimeter.

The minimum temperature of deformation is a function of time. But an approximate temperature of deformation may be obtained by observing plates $25 \times 8 \times .5$ mm. supported horizontally at each end or vertically at the lower end. The temperature at which the plate curves visibly from its own weight is called the temperature of deformation ("T. Def.").

The explosion temperature ("T. Exp.") is the temperature at which the confined gases escape suddenly, sometimes violently.

The calorific capacity ("C. Cap.") is the total quantity of heat in one kilogram of rock at the temperature considered, measured in grand calories.

FIXED TEMPERATURE POINTS AND CALORIFIC CAPACITY OF LAVAS, ETC.

Locality	Rock.	F. P.	T. Def.	T. Exp.	C. Cap.
	Orthoclase glass		1060°		
	Albite glass		1050–1177°		
	Anorthite glass		1083°		
	Leucite glass		1050–1150°		
Vesuvius	Lava of 1631	1103°			327
Vesuvius	Lava Sept. 22, 1904	984°			311
Etna	Old lava (no gas)	1260°			297
Etna	Rock glass	1063°			
Stromboli	Lava March 4, 1901	1176°			315
Stromboli	Old lava	1150°	1130°		
Lipari	Obsidian with 75.4 SiO_2		790–820°		
	Obsidian with much gas			830°	
	Obsidian with less gas			874°	
	Obsidian with little gas			902°	1000°
	Pumice	950°			361 at
Santorin, 1866	Crystalline andesite	1098°			353
	Vitreous andesite	1050°			362
	Green vitreous andesite	1110°			
Plomb du Cantal, France	Green vitreous andesite		1010°		
Plateau de Charade, Fr.	Black crystalline basalt	1040°			315
LePessy, near Bourboule	Perlite			956°	
Hecla	Ropy lava, much gas	1082°			335
	Lava, porous, 1845	1109°			293
Pico de Teyde, Canaries	Green obsidian			912°	
Chahorra, Canaries	Vitreous andesite, 1798	1004–1030°	966°		
	Slightly crystalline andesite, 1798	1080°			312
Guimar	Basaltic lava, 1705	1060–1065°			
Chinyero	Basalt, 18 Nov. 1909	1059°		1059°	313
	Basaltic inclusion	1076°		1076°	
Timanfaya, Lanzorote	Basalt with olivine groups	1068°			
Chimborazzo	Black porphyritic andesite	1214°			331
Ile Bourbon	Basaltic scoria (no gas)	1054°			304
Wada Togé, Japan	Black obsidian			1026–1049°	
Savaii, Samoa	Basalt, 1906	1053°		1062°	
Kilauea, Hawaii	Basaltic glass	1072°		1116°	
	Pelé's hair forms at	1120–1150°			
Pasir Kiamis, Java	Black obsidian, spherulitic			1103–1121°	
Tji Manoek, Java	Black spherulitic obsidian			963–991°	
Semeroe, Java	Crystalline andesite, August 5, 1908	1030°	980°		
Krakatoa	Green obsidian, 1883			880°	246
	Pumice		980°	(826–896°)	

FUSING POINTS OF IMPORTANT MINERALS.

Mineral.	Brun.[1]		Day, *et al.*[2]		Doelter.[3]		Joly and Cusack[4] (Meldometer).
	Inversion.	Fusion.	Inversion.	Fusion.	1902.	1903.	
Amphibole gr.							
Anthophyllite	1150°	1230°				1335°	
Tremolite	1090°	1270°				1210°	1219–1223°
Actinolite		1190°			1230°	1160°	1272–1296°
Hornblende		1060°			1065–85°	1075–1110°	
Apatite, Renfrew, Ont.		1550°				1285°	1227°
Beryl		1410, 1430°					
Cordierite		1310°					
Cyanite	1310°		To sillimanite at 1300°+			1420°	1090°
Epidote	900°	1250°			1095°		954, 976°
Feldspar group.							
Orthoclase, Arendal			Artificial pure feldspars		1175°	1190°	
Adularia Gothard		1270, 1300°				1200°	1164–1175°
Sanidine, Drachenfels					1130°	1160°	1140°
Microcline		1290°	Below 1200°		1155°	1160°	1169, 1175°
Anorthoclase		1250°					
Albite		1250°	Ab 1200°±		1110°	1140°	1172, 1175°
Oligoclase		1260°	Ab_3An_1 1345°±		1120°	1150°	1220°
Andesine		1280°	Ab_2An_1 1375°			1160°	
Labradorite		1370°	Ab_1An_1 1430°		1125°	1180°	1230, 1235°

[1] A. Brun, *Arch. Sc. Phys. Nat. Geneve,* XIII., 1902, pp. 85, 552; XVIII., 1904, p. 537. Summarized in "Recherches sur l'Exhalaison volcanique," 1911, pp. 31–35.

[2] Day, et al., *Am. J. Sc.,* XIX., 1905, p. 93; XXI., 1906, p. 100; XXII., 1906, p. 265, 385; XXVII., 1909, pp. 1, 421; XXVIII., 1909, p. 293; XXIX., 1910, p. 93; XXXI., 1911, p. 341.

[3] C. Doelter, *T. M. P. M.,* XX., 1901, p. 210; XXI., 1902, p. 23; XXII., 1903, p. 297.

[4] J. Joly, *Proc. Roy. Irish Acad.,* II., 1891, p. 38. Cong. Géol. Intern., VIII., 1900, p. 683. R. Cusack, *Proc. Roy. Irish Acad.,* IV., 1896, p. 399.

FUSING POINTS OF IMPORTANT MINERALS (*Continued*).

Mineral.	Brun.		Day, *et al.*		Doelter.		Joly and Cusack (Meldometer).
	Inversion.	Fusion.	Inversion.	Fusion.	1902.	1903.	
Labradorite[5]		1370°	Ab_1An_2	1477°			
Bytownite[5]		1500° nat.	Ab_1An_3	1516°	1132°	1190°	
Anorthite[5]		1550° nat.	An	1550°			
Fluorite	1230°	1270°		1387°			
Galena	830°						
Garnet group.							
Almandite		1065°			1075°	1125, 1145°	1265°
Pyrope		1010–1150°				1185°	
Grossularite					1110°	1120, 1140°	
Melanite					925°	940°	
Halite		825° art.		800° art.			
Hematite		1300°				1380°	
Ilmenite		1450°					
Leucite		1420°—			1310°	1300°	1298°
Mica group.							
Muscovite	850°				1230°	1260, 1270°	
Nephelite		1270°			1095°	1120°	1059,1070°
Eleolite					1080°	1105°	
Olivine group.							
Forsterite, Sardinia						>1460°	Stein[6] 1900° ±
Chrysolite, low in FeO		1750°					
Chrysolite, Vesuvius					1350°	1350°	1363–1378°
Pyroxene group.							
Bronzite		1410°			1330° ±	1360°	1295, 1300°
Hypersthene		1275°			1185°	1185°	
Diopside		1270°		1391°	Pöschl[7]—1315°	1255°	1187–1195°

[5] E. Dittler (*T. M. P. M.*, XXIX., 1910, pp. 273–333), of the school of Doelter, gives the following new determinations of melting points: Anorthite, Ab_8An_1 1370° C. (— 1290° C.), Ab_1An_9 1350° C. (— 1275° C.), bytownite, $Ab_{15}An_{15}$ 1325° C. (— 1260° C.), Ab_1An_4 1320° C. (— 1240° C.), Ab_1An_3 1300° C. (— 1245° C.), labradorite, $Ab_{25}An_{15}$ 1280° C. (— 1240° C.).

[6] G. Stein, *Zt. anorg. Chem.*, LV., 1907, p. 159.

[7] V. Pöschl, *T. M. P. M.*, XXVI., 1908, p. 413 (1300° to 1325° when pure).

FUSING POINTS OF IMPORTANT MINERALS (*Continued*).

Mineral.	Brun.		Day, *et al.*		Doelter.		Joly and Cusack (Meldometer).
	Inversion	Fusion.	Inversion.	Fusion.	1902.	1903.	
Pyroxene group							
Wollastonite		1350°	To α-form at about 1190°	1540°	1220, 1232°	Kultascheff[8] 1240°	1400°+
Hedenbergite		1190°				1080–1110°	1203–1208°
Augite		1230°			1080, 1095°	1100–85°	1187–1199°
Diallage		1210°			1095°	1125–70°	1264–1300°
Acmite (Ægirite)		970°			925°	930–45°	
Spodumene	1010°					1085°	1173°
Quartz	552°	1780°	To β-form at 575° which inverts to β-cristobalite at about 800°, which fuses at about 1600°			Hempel[9] 1670° Stein[6] 1600°	1424, 1430°
Scapolite group.							
Mèionite		1330°			1155°		1281°
Sodalite group.							
Sodalite	1250°	1310°			915°	1030°	1127, 1133°
Hauynite	1410°	1450°					
Spinel group.							
Spinel		1900° ±					
Chromite	1670°	1850°				1450°	
Magnetite		1260°			1185°	1210°	1250–1450°
Thenardite		860° art.		884° art.			
Titanite	1190°	1210°				1215°	1127, 1142°
Vesuvianite	980°	1000°				1030°	1024, 1035°
Zircon		1900° ±				1760° ±	
Based upon:							
Sulphur		444.5°					
Silver				960° ±0.7		968°	954°
Gold		1067.4°		1062.4° ±0.8		1072°	1045°
Copper				1082.6° ±0.8		1080°	1054°
Palladium				1549.2° ±2.0			1500°
Platinum		1779°					

[8] N. V. Kultascheff, *Zt. anorg. Chem.*, XXXV., 1903.

[9] W. Hempel, *Chem. Zeit. Repertorium.*, 1902, p. 303. Also, *Ber. V. Intern. Kong. Angew. Chem.*, I., 1904, p. 715.

Brun has made numerous measurements of the fusing points of natural and artificial minerals, and the temperature at which certain minerals lose their identity without fusing. His data of this sort are now known to be of a high order of accuracy. In the following table similar measurements by other experimenters are included for comparison. (See pages 3–5.)

In many respects Brun's analyses of the gases caught in chilled volcanic rocks are most interesting and important. Former analyses of such gases, called by Lincoln[1] repressed magmatic emanations, have commonly included all the volatile constituents given off upon heating; or all those given off at temperatures above 100° or 110° C. Brun argues that gases given off by rocks below 600° or 800° C. have entered the rocks since they cooled below those temperatures, and therefore have no significance in volcanism. The gases which produce volcanic activity are those which escape at volcanic temperatures, in many cases with explosive violence. Some obsidians and lavas when heated to volcanic temperatures explode with such violence as to destroy the heating furnace and endanger the experimenter. Only those gases given off at or near the explosion temperature are true volcanic gases; no other gases are included in the analyses which are tabulated below.[2] (See pages 7–10.)

According to the analyses of Brun the other gases producing volcanism, aside from those tabulated, include hydrocarbons (especially CH_4), H_2S, and S. Hydrocarbons are sometimes quite abundant.

If the gases in a given volcanic rock are expelled by temperatures exceeding the explosion temperature, and the mass is then oxidized in any way it yields more gas, as shown in the following table. (See page 11.)

The remarkable feature of these analyses is that they show no oxygen, no steam, and very little hydrogen, although it is commonly held that volcanic explosions are produced by the explosive energy of steam. The main thesis presented by Brun is that

[1] F. C. Lincoln: Econ. Geology, II, 1907, p. 258.

[2] For other analyses of gases in rocks see: R. T. Chamberlin, "Gases in Rocks," Carnegie Inst. Publ. 106.

Volcanic Gases in Rocks.

Gases are given in cubic centimeters (at 0° C. and 760 mm. pressure) per kilogram of rock. Weights of NH_4Cl and chlorides are given in milligrams per kilogram of rock. The rock is heated to fusing point or explosion temperature. The percentage composition of gases is based on volumes. (— means absent, + present.)

Locality.	Rock.	Total Gas in c.c. per kg. of Rock.	NH_4Cl in mg.	Other Chlorides in mg.	Composition of Gases in Per Cent. by Volume.							Remarks.
					Free Cl_2	HCl	SO_2	CO_2	CO	H_2	N_2	
Plomb du Cantal, France	Green obsidian	1,020	38		12.5	50.2	trace	32.8		4.5		Some CO with N. Hydrocarbons present.
Le Pessy, France	Perlitic obsidian	1,129	47			76	—	14.3	8.6	1.2		Hydroc. not abundant. H_2S—
Viterbo, Italy	Dark obsidian with phenocrysts.	757	66	100	8.4	3.1	44.0	37.0	4.3	1.6	1.6	Hydroc. abundant.
Cabo de Gata	Gray obsidian	484	50	+	7.1	72.2	—	9.2	5.5	6.0		H_2S absent.
Tokay, Hungary	Black obsidian	467	8		4.2	52.9	—	13.6	7.8	15.7	7.8	CH_4 trace. H_2S absent.
Chemnitz, Hungary	Black obsidian	321	16	+	7.3	32.0	little	29.9[1]	13.3	15.6		Hydroc. present. H_2S—.
Borzsa, Hungary	Gray obsidian	607	11		18.1	19.8	3.8	38.5	other gases = 19.7			Hydroc. trace.
Olasz-Liszka, Hungary	Black obsidian	510	8	+	trace	45.9	—	22.3	18.0	13.8	trace	Hydroc. trace. H_2S—.
Tolcsva, Hungary	Black obsidian	423	25	+	4.6	44.1	trace	21.2	10.2	10.0	9.9	Hydroc. present.
Neudorfel	Black pitchstone	350	130		6.6	3.8		28.5	8.5	10.4	42.2	N_2 not pure.
Gotterfelsen, Germany	Pitchstone	423	33	+	13.3	13.3		37.5	14.6	6.6	11.4	CH_4 = 3.1.
See Dellen, Sweden	Black vitrophyre	376	37	+		11.3	trace	42.6	18.6	23.1	4.4	Hydroc. abundant.
Arran Is., Scotland	Green pitchstone	457	45.7	—		5.8		46.7[1]	18.2			Hydroc., N_2, etc., 29.3.
Etna, Sicily	Dolerite	553	30	1,000		trace	2.7	81.1	9.6	3.0	2.4	CH_4 = 1.2.
Lipari	Obsidian	754	+	$FeCl_2$ +	trace	89.2		7.7[1]			3.1	N_2 not pure.
Strombali, March 4, 1901	Basalt[2]	266	13.5	243	12.8	2.0	4.5	60.2	11.5	0.5	6.9	CH_4 = 1.6.
Vesuvius, Sept. 20, 1904	Leucite tephrite	397	17	3,500	4.2	trace	3.6	66.3			26.2	N_2 not pure.

[1] Includes some SO_2.

[2] Analysis gives $SiO_2 = 50.18$, $Al_2O_3 = 18.86$, $Fe_2O_3 = 0.48$, $FeO = 7.80$, $MgO = 3.54$, $CaO = 10.81$, $Na_2O = 4.92$, $K_2O = 2.05$, $TiO_2 = 1.10$, $Cl_2 = 0.145$, $V_2O_3 = 0.045$, $P_2O_5 = 0.30$, $MnO = 0.03$, CuO = trace. Total, deducting 0.065 for Cl_2 = 100.19.

VOLCANIC GASES IN ROCKS (*Continued*).

Locality.	Rock.	Total Gas in c.c. per kg. of Rock.	NH_4Cl in mg.	Other Chlorides in mg.	Composition of Gases in Per Cent. by Volume.							Remarks.
					Free Cl_2	HCl	SO_2	CO	CO	H_2	N_2	
Vesuvius, 1906	Leucite tephrite	374	20.4	5143	—	6.6	12.0	73.8	trace	7.6	trace	Hydroc. +.
Santorin, 1866	Vitreous andesites	470	26	290[3]	13.9	54.0		24.7[5]	4.6		2.9	N_2 not pure.
Santorin, 1866	Various andesites	350	+	+	30.2	35.3		27.0[5]	4.7		2.8	N_2 not pure.
Milo	Brown obsidian	220	24.8	+	—	61.3		20.0[5]	7.0	11.6		Hydroc. +.
Milo	Gray obsidian	331	6.5	+	trace	56.5	—	12.2	12.2	16.7	2.3	N_2 not pure. H_2S—.
Iceland	Black obsidian	371	8.3	+	5.4	64.1		14.4[5]		16.2		Hydroc. + H_2S —.
Iceland	Black obsidian	216	4	50	trace	40.3		15.4[5]		44.3[4]		
Iceland	Black obsidian	340	7		10.7	53.6		12.5	10.7	12.5		Hydroc. +.
Iceland	Black obsidian	258	12.4		—	41.8		29.7[5]	12.9	9.6	6.0	N_2 not pure. Hydroc. +.
Pico de Teyde, Canaries	Green andesitic obsidian	165			3.5	6.1	trace	65.8		14.7		
Pico de Teyde, Canaries	Obsidian	230			—	41.5		36.5	11.0	4.9	5.5	Hydroc. +.
Pico de Teyde, Canaries	Obsidian	164	25	450	3.7	14.0	1.1	61.4	13.8	6.1		Hydroc. +.
Chinyero, Canaries, 1909	Basaltic lapilli	270	8.5	400	22.7	—	14.7	49.3	10.7		2.7	N_2 not pure.
Chinyero, Canaries, 1909	Basaltic lapilli	220	35	90	24.0	—	11.6	50.7	11.6		2.0	N_2 not pure.
Chinyero, Canaries, 1909	Basaltic inclusion	356	18	466		trace	5.0	80.0	7.5	5.6		CH_4 = 1.9.
Tamanfaya	Basaltic lava	350	27	200	30.4	2.8	9.1	40.6	5.1	1.3	10.7	N_2 not pure.
						2.0		28.1	18.2	34.2	15.0	CH_4 = 1.5; hydroc. excessively abun.; H_2S = 1.0.
Pichincha	Andesitic pumice	4.450	200	333								
Cerro Potosi, Peru	Colorless obsidian	450	+	50	13.3	24.7	0.2	18.2	14.2	13.3	16.1	Hydroc. +.
Mexico	Brown obsidian	273	9.8	+	26.3	20.9	trace	45.6		7.2		
Mexico	Brown obsidian	450	8.0	233	—	26.7	2.2	54.1	10.4	5.6	1.1	Hydroc. distilled = 153. mg.

[3] Includes much silicon fluoride.

[4] By difference.

[5] Includes some SO_2.

VOLCANIC GASES IN ROCKS (*Continued*).

Locality.	Rock.	Total Gas in c.c. per kg. of Rock.	NH_4Cl in mg.	Other Chlorides in mg.	Composition of Gases in Per Cent. by Volume.							Remarks.
					Free Cl_2	HCl	SO_2	CO_2	CO	H_2	N_2	
Zimapan, Mexico	Pale obsidian	590	11		20.1	40.2	trace	25.4	10.5	3.8		
San Andreas, Mexico	Dark obsidian	167	5.4	75.5	—	61.1	0.6	14.3	10.6	12.4	1.1	N_2 not pure.
Millard Co., Utah	Black obsidian	448	33.3	+	—	67.5		16.6[b]	7.9	6.9	0.8	CH_4 = 0.3. Hydroc. abun. H_2S—.
Obsidian Cliff, Yellow. P.	Lithoidite	467	17	+	—	58.9	—	23.5	9.6	5.5	1.3	CH_4 = 1.3. Hydroc. + H_2S —
Obsidian Cliff, Yellow. P.	Lithoidite	398	10	+	7.2	60.5	—	15.9	9.6	6.0	0.8	H_2S — Hydroc. abun.
Savaii, Samoa	Ropy basalt	303	17	+	—	9.9	1.1	48.0	15.4	16.4	8.2	Heated 800°–850° CH_4 = 1.0.
Savaii, Samoa	Ropy basalt	397	17	+	11.8	5.9	12.6	49.6	7.6	8.0	4.0	Heated 1062–1100°. CH_4 = 0.5.
Kilauea, Hawaii	Vitreous lava	295	12	50		trace	1.7	50.8	17.3	28.5	1.2	Hydroc. abundant.
Kilauea, Hawaii	Compact lava				5.6	1.7	4.7	69.1	11.6	6.1	0.3	CH_4 = 0.9.
Haleakala, Hawaii	Basaltic lava	806	50	119		trace	—	55.6	10.5	3.7	15.5	CH_4=3.0. H_2S=11.8. Hydroc. abun; also S.
Asama, Japan	Scoria	507	23		17.1	28.3	trace	39.5	10.5	2.7	0.6	N_2 not pure.
Vada-Togé, Japan	Black obsidian	507	15	+	—	61.6	—	10.3	11.9	11.3	3.5	CH_4=1.1. Hydroc.+. H_2S —.
Semeroe, Java, 1908	Andesitic lava	139	20.5	143.5	18.2	9.2	—	47.2	18.0	3.4	3.4	
Pasir Kiamis, Java	Acid obsidian[6]	370	+	+	18.3	50.1	0.9	15.5		15.2		Hydroc. +.
Pasir Kiamis, Java	Acid obsidian	420	38	171	12.2	47.6	trace	25.2	10.9	4.1		
Tji Manoek, Java	Black obsidian	417	50	+	14.3	50.8	8.3	9.8		15.2		O_2=1.4.
Tji Manoek, Java	Black obsidian	331	6.4	+	11.3	60.6	0.4	15.3	5.9	3.2	3.4	O_2 absent.
Tji Manoek, Java	Black obsidian	361	4	155	14.3	58.8	0.2	14.0	4.4	4.8	3.4	O_2 absent.
Patœha, Java	Black obsidian.	371	32	+	18.3	45.8	+		35.9[7]			Hydroc. +.
Krakatoa	Andesitic obsidian[8]	498	49		59.6	11.6	8.0	6.7	4.8		8.7	N_2 not pure. O_2=0.5.
Krakatoa	Andesitic obsidian[9]	543	54		49.9	15.5	11.6	6.9	5.7		10.4	N_2 not pure. O_2 trace.

[6] Layers 1–5 mm. thick have different gases or more gas than intervening layer.

[7] By difference, SO_2 included. SiF_4 present in sublimate.

[8] Previously undried.

[9] Previously dried at 170° C.

VOLCANIC GASES IN ROCKS (*Continued*).

Locality.	Rock.	Total Gas in c.c. per kg. of Rock.	NH_4Cl in mg.	Other Chlorides in mg.	Composition of Gases in Per Cent. by Volume.							Remarks.
					Free Cl_2	HCl	SO_2	CO_2	CO	H_2	N_2	
Krakatoa	Andesitic obsidian[10]	380	—		82.0	—	2.7	8.9	—		6.6	N_2 not pure. O_2 —.
Krakatoa	Andesitic obsidian[11]	435	—		63.2	—	+	29.6[12]			7.0	N_2 not pure. O_2 trace.
Krakatoa	Andesitic obsidian[9]	490.5	10		51.7	21.1	trace	16.0	7.1		4.0	O_2 trace.
Krakatoa	Andesitic obsidian[11]	602	—		42.0	—	12.3	20.0	9.0		16.6	O_2 trace.
Abyssinia	Dark obsidian[13]	273	3.3	+	23.2			51.7[12]	14.1	8.8	2.2	N_2 not pure. Hydroc. + H_2S —.
Alagos, Armenia	Black obsidian	310	8	100	32.3	2.2	0.8	56.2	5.7	1.8	1.1	N_2 not pure.
Agh Dagh, Armenia	Gray obsidian	180	14	58	—	39.7	0.9	21.3	23.8	12.7	1.6	N_2 not pure. Hydroc. trace. H_2S—.
Mount Erebus, Antarctic	Black kenyite	434	17	180		3.6	16.2	68.6	6.4	4.6	trace	Hydroc. and S abund. H_2S —.
Mount Erebus, Antarctic	Black kenyite	465	18	216	10±		16.1	50±	5±		+	Hydroc. and S abundant. H_2S —.
Number of determinations		63[14]	55[15]	23[15]	53[16]	65[17]	44[18]	53[19]	54[20]	57[21]	47[21]	
Average		392[14]	22[15]	225[15]	10.5[16]	29.0[17]	4.4[18]	32.0[19]	10.2[20]	7.4[21]	4.6[21]	

[10] Previously dried at 500° C.
[11] Previously calcined at 650° for 480 hours.
[12] Some SO_2 included.
[13] Contains 72.28 per cent. SiO_2.
[14] 3, very high, omitted.
[15] 2, very high, omitted.
[16] Including 12 "absent" or "trace."
[17] Including 10 "absent" or "trace."
[18] Including 18 "absent" or "trace."
[19] Including 12 in which CO_2 contained some SO_2.
[20] Including 2 "absent" or "trace."
[21] Including 18 in which H_2 and N_2, not separated, are estimated as equal.

GASES PRODUCED BY OXIDATION OF VOLCANIC ROCKS.

Locality.	Rock.	Gas of First Heating in c.c. per kg. Rock.	Gas after Oxidation in c.c. per kg. Rock.	Composition of Second Gas.							Remarks.
				Free Cl	HCl	SO_2	CO_2	CO	H_2	N_2	
Etna, Sicily	Dolerite	553	1180			39.5	58.8			1.7	N_2 not pure.
Stromboli, March 4, 1901	Basalt	266	512	trace	—	18.2	78.6			3.3	
Vesuvius, Sept. 20, 1904	Leucite tephrite.	397	643	4.6		1.5	89.6			4.3	
Vesuvius, 1906	Leucite tephrite.	374	260				100.0				
Chinyero, Canaries	Basaltic lapilli	270	466			36.6	63.4				
Chinyero, Conaries	Basaltic lapilli	220	1760			25.5	74.5				
Obsidian Cliff, Yellow. P	Lithoidite	398	425	3.4		6.5	86.1			4.0	
Kilauea, Hawaii	Vitreous lava.	295	62			31.0	69.0				
Haleakala, Hawaii	Basaltic lava.	806	411			26.4	43.8			29.8	

water is absent from volcanic activity; that it is not present as aqueous gas nor as dissociated hydrogen and oxygen. This statement is supported by the following evidence.

1. Direct measurements in volcanic craters show a rapid decrease in the amount of water vapor at points progressively nearer the center of the crater. Such measurements have been made in fumeroles varying in temperature from 20° to 340° C. Many measurements show that gases escaping during volcanic activity are less humid than the air which surrounds them.

Secondary or parasitic fumeroles having temperatures below 300° or 400° C. often contain aqueous gas, but such gas is of surface origin, as is shown by the increase in quantity after rains, by the increase in quantity as the temperature falls, etc.

2. The white cloud which escapes during volcanic paroxysms is a mixture of gases and solids. The gases have been enumerated: the solids are KCl, NaCl, NH_4Cl, SiO_2, NH_4F, $FeCl_2$ and others which are nearly all soluble in water and subject to ready oxidation in the presence of H_2O or O_2.

3. Volcanic ashes, when first erupted, are invariably white; they oxidize readily to a red color.

4. The white volcanic cloud is not steam since it is insoluble in the atmosphere.

5. The volcanic cloud never produces rainbows nor aureoles.

Brun distinguishes between "active" rocks and "dead" rocks.

Active rocks, if basic, begin to boil as soon as they are fused. At the same time they expand to a remarkable extent on account of the formation of gas bubbles through their mass. Active rocks, if acid, explode at volcanic temperatures, in some cases with great violence.

Dead rocks, when fused, neither explode nor boil nor expand beyond the small amount due to change of state.

Most extrusive igneous rocks are still active. Most other rocks are dead. Active rocks become inactive through oxidation, as illustrated by red scoria, dead through complete oxidation.

According to Brun dead rocks do not and can not produce volcanic activity, no matter how highly they may be heated.

Furthermore, dead rocks are held to have obtained their water

content at temperatures considerably below those characterizing volcanism, and from external surficial sources. It is considered highly probable that *all* hydrated minerals including the micas of granites have been produced by hydration effected by surface waters after cooling much below volcanic temperatures.

It seems probable to the writer that Brun has discovered a fact of great importance in regard to volcanoes. His carefully collected and elaborately presented evidence proves beyond doubt that the importance of water in volcanism has been grossly exaggerated by many authors. The only way to invalidate this conclusion is to impeach the accuracy of the data submitted.

But the Swiss savant seems to have overstated the fact and to have drawn some conclusions of doubtful validity. Thus, it is very difficult to believe that lavas during volcanic activity are absolutely devoid of water, when it is remembered that these same lavas in some cases contain micas and amphiboles as phenocrysts. It is true that such phenocrysts may show evidence of instability and partial resorption under surface conditions, but such a re-solution would simply transfer the water of the mineral to the uncrystallized magma. It may be that steam must be regarded as of no importance in producing volcanic explosions, but how can it be regarded as wholly absent in view of the fact that amphiboles contain dissolved water which is not wholly lost at 900° C. *even under atmospheric pressure.*[1] As established by Brun 900° C. is within the range of the temperatures of lavas during volcanic activity, as shown in the following table.

TEMPERATURES OF LAVAS DURING VOLCANIC ACTIVITY.

Kilauea, July, 1910	1260° C.
Stromboli; March, 1901	1150°–1176° C.
Vesuvius, September, 1904	1100° C.
Semeroe, Java, August, 1908	900° C. (exterior)
Krakatoa, 1883	880° C.

It is clear that the great pressures commonly existing within volcanoes will favor the retention of water in the magma.

Contrary to the conclusion of the Swiss vulcanologist there seems to be abundant evidence that the micas of granites and

[1] E. T. Allen and J. K. Clement, *Amer. Jour. Sc.*, XXVI., 1908, p. 101.

monzonites are primary. An ordinary thin section will show that the texture of such rocks indicates approximately simultaneous crystallization of micas, quartz, and feldspars. There is no evidence of later growth of the micas. They are evenly distributed through the whole igneous mass in a manner wholly independent of the shape or size of the latter. Their distribution is in no way influenced by fissures, or freedom of water circulation, or location with respect to the surface. Further, the formation of micas by hydration of other minerals is accompanied by increase of volume; no evidence of such increase of volume is to be seen in granite and similar rocks.

Instead of taking the extreme position that water does not exist in magmas at volcanic temperatures it seems more reasonable to the writer in view of all the facts to hold that it is present in small amounts in all magmas though it may not play any important role in producing explosions. Further, it seems to have special affinities for silica and therefore for highly siliceous magmas. The amount of water present in a magma probably depends upon the temperature, as well as upon the pressure and the chemical composition. It seems quite possible that even at depths much below the reach of surface water the aqueous gas in any given mass may vary with its composition, its temperature and its pressure. Thus, magmas would lose most of their water content before reaching volcanic temperatures under relatively low pressures such as those existing near the surface. But magmas at lower temperatures or under greater pressures would retain a large part of their water. It may be that batholiths after gradually expelling part of their water content into surrounding rocks on account of decrease in pressure or increase in temperature, would upon cooling, redissolve part or all of the expelled water before crystallization.

OXIDATION OF SULPHIDES.

(Second Paper.)

V. H. Gottschalk and H. A. Buehler.

In a recent paper[1] the authors have shown that the rate of oxidation of certain natural sulphides is greatly increased by the presence of either marcasite or pyrite. Experiments were first undertaken upon the assumption that any such oxidation or solution was due (1) to the presence of oxygen carriers, in the form of iron salts; (2) to the free sulphuric acid formed by the oxidization of the iron sulphides; or (3) to autoxidation, or induced reaction. As the results obtained did not conform, in some respects, to the demands of theory, it became evident that the above assumptions were not adequate to explain the complete action although, in all probability, each process is a factor of greater or less importance.

Drs. E. T. Allen[2] and R. C. Wells[3] believe that the excess of sulphuric acid formed, by the oxidation of the iron sulphides, is sufficient to explain the increased solubility observed. However, as will be shown in the present paper, this assumption is hardly supported by experimental facts. Increased action is probably due chiefly to other factors—one of which is evidently electrolytic.

In this paper we shall endeavor to show: (1) that while there is, in mixtures of two sulphides, a large increase in the solution of one, there is also a protective action exerted on the other; (2) that there is a difference of potential between the different sulphides which can be arranged in a series similar to the electrochemical series shown by the metals; and (3) that this fact may be of the greatest importance in the process of oxidation.

[1] Buehler and Gottschalk, Economic Geology, Vol. V., p. 28.
[2] Allen, Economic Geology, Vol. V., p. 387.
[3] Wells, Economic Geology, Vol. V., p. 480.

Theoretically, the oxidation of pyrite or marcasite, alone, may proceed in various ways—of which the following equations are examples:

(1) $$FeS_2 + 7O + H_2O = FeSO_4 + H_2SO_4,$$

(2) $$\begin{cases} 2FeS_2 + 3O = Fe_2O_3 + 4S, \\ FeS_2 + 4O = FeSO_4 + S, \end{cases}$$

(3) $$FeS_2 + 3O + H_2O = FeSO_4 + H_2S,$$

(4) $$FeS_2 + 6O = FeSO_4 + SO_2.$$

It is possible that the oxidation may also result, under certain conditions, in the formation of sulphites and thio-sulphates, in which case these compounds would be found in the resulting solution.

EXPERIMENTAL.

In general, the following experiments were carried out, under conditions similar to those cited in our previous paper. The finely powdered sulphides were placed upon filter paper, spread upon a Hirsch filter plate which was fitted in a 6 cm. funnel. In a number of the experiments the filter paper was replaced by asbestos which was packed between two filter plates. The sulphides were then washed twice daily with distilled water, the filtrate being caught in a 700 c.c. Jena flat-bottomed flask. The sulphides were treated alone and also when mixed with pyrite or marcasite or some other natural sulphide.

Experiment 1.—A series of the filtrates obtained from marcasite alone, and from marcasite mixed with galena, sphalerite, and copper sulphides, were tested for the presence of free SO_2, sulphites, and thio-sulphates. In no case were these compounds present. Under the conditions of the experiment the oxidation does not therefore appear to go according to equation No. 4. We find, however, that if finely powdered pyrite or marcasite is kept in ground stoppered bottles for any considerable length of time they evolve a strong odor of SO_2. Apparently, in this case,

there has not been sufficient moisture and oxygen present for complete oxidation.

Experiment 2.—In order to test for the presence of free sulphur, in experiments with pyrite, the entire residue left on the funnel (5 to 20 grams) was treated with three portions of carbon disulphide. No sulphur was found in a series of eight experiments. The ten pound sample of marcasite, used in experiment 3, was also treated with carbon disulphide. This experiment shows the presence of free sulphur. The sample contains considerable organic matter and before use had only been washed to free it from soluble salts. The reaction may therefore form free sulphur although in thin layers and pure minerals the results were negative. The results have not been carried far enough to determine the influence of the presence of impurities or the conditions under which the experiment is carried out. According to H. N. Stokes, sulphur is formed during the oxidation of marcasite but not in the case of pyrite where these minerals are treated with a dilute solution of ferric sulphate.

Experiment 3.—Tests for the presence of hydrogen sulphide were made as follows: The oxidation was carried out in an appa-

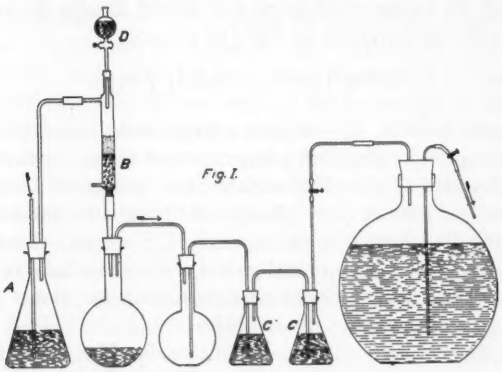

Fig. 1.

ratus (Fig. 1) through which air could be drawn continuously. The air entering flask *A* passed slowly through alkaline lead

nitrate solution to free it from H_2S; it then passed through tube *B*, in which the finely ground sulphide was placed upon a filter of asbestos wool; finally the air was again washed in lead solutions held in flasks *C*. The sulphides were washed twice daily by means of the separating funnel *D*. Marcasite, after four months' continuous treatment, shows no trace of blackening of the alkaline lead solution, indicating the absence of even traces of hydrogen sulphide. The marcasite oxidized normally, except that the asbestos filter apparently induced hydrolysis of the iron salts. This effect is shown by the deep stain of ferric hydroxide which colored the asbestos. The following analysis of the solution and precipitate in the flask also shows this hydrolysis:

Solution 1,068 c.c.

$FeSO_4$, 0.0602 grams; $Fe_2(SO_4)_3$, 0.1799 grams; SO_3 (excess), 0.2697 grams; Fe_2O_3 (in the precipitate), 0.0218 grams.

This analysis shows, in the solution, a ratio of the atoms of sulphur to the atoms of iron $S/Fe = 3.14/1$, instead of the theoretical ratio of 2.

A mixture of marcasite and galena treated in the same apparatus, under similar conditions, failed to give traces of H_2S, although the excess of sulphuric acid should dissolve the lead sulphide with the formation of H_2S, as follows:

$$PbS + H_2SO_4 = PbSO_4 + H_2S.$$

In order to make this test upon a larger scale, about ten pounds of marcasite were placed in a large covered funnel, upon the surface of which alkaline lead nitrate paper and small beakers of alkaline lead nitrate were placed. Although the mineral oxidized rapidly, there was no trace of H_2S shown. Later, 200 grams each of finely powdered galena and sphalerite were mixed with the marcasite. Continuous treatment for three months shows no trace of hydrogen sulphide.

The above experiments would indicate that H_2S is not formed even under the most favorable conditions; therefore equation No. 3 does not seem to hold.

As shown in experiment (3), ferrous sulphate and sulphuric

acid are formed during the oxidation. Ferric sulphate is also formed by the further oxidation of the ferrous sulphate as follows:

$$2FeSO_4 + O + H_2SO_4 = Fe_2(SO_4)_3 + H_2O.$$

Through hydrolysis, a portion of the ferric sulphate so formed hydrolizes to

$$Fe_2(SO_4)_3 + 3H_2O = Fe_2O_3 + 3H_2SO_4.$$

The Fe_2O_3 appears as a yellowish red precipitate in the flask and on the filter. No doubt this oxide is hydrated to some extent and may have the formula of limonite.

The occurrence of ferric and ferrous sulphates and free sulphuric acid indicates that the oxidation proceeds according to equation No. 1.

In the following experiments the iron is shown as Fe_2O_3, although it occurs chiefly as ferrous and ferric sulphates. The proportion of ferric and ferrous salts depends largely upon the method of treatment, the time the solution stands and the possible free access of air. The results, as quoted below, are figured to show (1) the total oxidation, (2) the ratio of the sulphur and the metallic molecules that have been transferred as compared to theoretical considerations, and (3) the percentage of the metal washed through or oxidized.

Complete oxidation of marcasite or pyrite (FeS_2) involves two atoms of sulphur and one atom of iron. In analyzing solutions derived from such oxidation the ratio of the iron to sulphur should stand as 1:2. In the following results there should be required, for every molecule of Fe_2O_3, four molecules of S, since it has required two molecules of FeS_2 to form one molecule of the ferric oxide, and, in the results quoted, the ratio for the theoretical oxidation of pyrite or marcasite compared to barium sulphate ($BaSO_4$), in which form the sulphur was weighed ($BaSO_4$ requires one sulphur), should therefore be $BaSO_4/Fe_2O_3 = 4/1$.

The columns headed "solution" and "precipitate" indicate

the materials found both in the filtrate and in the small precipitate which usually coats the bottom of the flask. The column headed "residue" indicates materials derived from the treatment of the residue on the filter plates. The total amount of materials found in the flask is given in the last column.

PYRITE.

Experiment 4.—10 grams; through 60 mesh and on 100 mesh; 4 months; total solution 504 c.c. Considerable brown precipitate in flask.

	Solution, Grams.	Precipitate, Grams.	Total, Grams.
Fe_2O_3	0.1388	0.0291	0.1679
$BaSO_4$	0.8726	0.0109	0.8835

Ratio of number of molecules of $BaSO_4$ to number of molecules of Fe_2O_3 is $BaSO_4/Fe_2O_3 = 3.60$ (theory for FeS_2, 4.00).

Iron washed through, 2.5 per cent.

MARCASITE.

Experiment 5.—Same as for pyrite, total solution 513 c.c.

	Solution, Grams.	Precipitate, Grams.	Total, Grams.
Fe_2O_3	0.1149	0.0321	0.1470
$BaSO_4$	0.7177	0.0118	0.7295

Ratio of number of molecules of $BaSO_4$ to number of molecules of Fe_2O_3 is $BaSO_4/Fe_2O_3 = 3.40$ (theory for FeS_2, 4.00).

Iron washed through, 2.2 per cent.

SPHALERITE.

Experiment 6.—10 grams; through 60 mesh and on 100 mesh; 5 months; total solution 540 c.c.

$ZnO = 0.0273$ grams; $BaSO_4 = 0.0556$ grams.

Ratio of number of molecules of $BaSO_4$ to number of molecules of ZnO is $BaSO_4/ZnO = 0.71$ (theory for ZnS, 1.00).

Zinc washed through, 0.33 per cent.

GALENA.[1]

Experiment 7.—10 grams; through 80 mesh and on 100 mesh; 8½ months; total solution 750 c.c.

	Solution, Grams.	Precipitate, Grams.	Residue, Grams.	Total, Grams.
$PbSO_4$	0.0057	0.0044	0.1090	0.1191
$BaSO_4$	0.0368	0.0034	0.0839	0.1241

Ratio of number of molecules of $BaSO_4$ to molecules of $PbSO_4$ is 1.08 (theory for PbS, 1.00).

Lead oxidized, 0.94 per cent.

SPHALERITE WITH MARCASITE.

Two mixtures of 10 grams sphalerite with 5 and 20 grams, respectively, of marcasite, all through 60 mesh and on 100 mesh, were subjected to treatment, all for 5 months.

Experiment 8.—10 grams sphalerite with 5 grams marcasite; total solution 544 c.c.

	Solution, Grams.	Precipitate, Grams.	Total, Grams.
ZnO	0.2669	——	0.2669
Fe_2O_3	0.0109	0.0070	0.0179
$BaSO_4$	0.9167	0.0017	0.9184

Ratio of number of molecules of ZnO to number of molecules of Fe_2O_3 to number of molecules of $BaSO_4$ is $ZnO : Fe_2O_3 : BaSO_4 = 1 : 0.034 : 1.20$ (theory $1 + (4 \times 0.034)$, or 1.14).[2]

[1] The original galena contained some lead sulphate, for 10 grams of 200 mesh galena, before treatment, gave 0.49 per cent. extraction with ammonium acetate. This has not been subtracted in our data.

[2] This ratio indicates that virtually the total sulphur, combined with the zinc and iron as sulphides, has found its way into the solution; for one molecule of sphalerite gives one molecule of ZnO and one molecule of $BaSO_4$, while, as already explained (page —), each molecule of Fe_2O_3 was derived from that amount of FeS_2 which gives four molecules of $BaSO_4$. Therefore the sum of the molecules of ZnO + 4 times the molecules of Fe_2O_3 should be equal to the molecules of $BaSO_4$ found, if all the sulphur passes into the solution.

Zinc carried through, 3.20 per cent. Iron carried through, 0.54 per cent.

Experiment 9.—10 grams of sphalerite with 20 grams marcasite; total solution 530 c.c.

	Solution, Grams.	Precipitate, Grams.	Total, Grams.
ZnO	0.3864	——	0.3864
Fe_2O_3	0.0360	0.0101	0.0461
$BaSO_4$	1.3960	0.0005	1.3965

Ratio of number of molecules of ZnO to number of molecules of Fe_2O_3 to number of molecules of $BaSO_4$ is $ZnO:Fe_2O_3:BaSO_4 = 1:0.061:1.26$ (theory $1+(4\times 0.061)$, or 1.24).

Zinc carried through, 4.63 per cent. Iron carried through, 0.35 per cent.

GALENA WITH MARCASITE.[1]

Three mixtures of galena (through 60 mesh and on 150 mesh) with 5, 10, and 20 grams respectively of marcasite (through 60 mesh and on 100 mesh) were treated as before described for 8½ months.

Experiment 10.—10 grams galena with 5 grams marcasite; total solution 530 c.c.

	Solution, Grams.	Precipitate, Grams.	Residue, Grams.	Total, Grams.
$PbSO_4$	0.0090	0.0005	0.6736	0.6831
Fe_2O_3	0.0037	0.0008	——	0.0045
$BaSO_4$	0.0562	0.0004	0.5186	0.5754

Ratio of number of molecules of $PbSO_4$ to number of molecules of Fe_2O_3 to number of molecules of $BaSO_4$ is $PbSO_4:Fe_2O_3:BaSO_4 = 1:0.013:1.09$ (theory $1+(4\times 0.013)$, or 1.05).

Lead oxidized, 5.39 per cent. Iron carried through, 0.14 per cent.

Experiment 11.—10 grams galena with 10 grams marcasite; total solution 500 c.c.

[1] See note under "Galena," Experiment No. 7.

	Solution, Grams.	Precipitate, Grams.	Residue, Grams.	Total, Grams.
$PbSO_4$	0.0095	0.0022	1.0753	1.0870
Fe_2O_3	0.0043	0.0018	——	0.0061
$BaSO_4$	0.0820	0.0045	0.9280	0.9145

Ratio of number of molecules of $PbSO_4$ to number of molecules of Fe_2O_3 to number of molecules of $BaSO_4$ is $PbSO_4 : Fe_2O_3 : BaSO_4 = 1 : 0.0106 : 1.11$ (theory $1 + (4 \times 0.0106)$, or 1.044).

Lead oxidized, 8.58 per cent. Iron carried through, 0.09 per cent.

Experiment 12.—10 grams galena with 20 grams marcasite; total solution 500 c.c.

	Solution, Grams.	Precipitate, Grams.	Residue, Grams.	Total, Grams.
$PbSO_4$	0.0051	0.0005	1.6502	1.6558
Fe_2O_3	0.0030	0.0033	——	0.0066
$BaSO_4$	0.1130	0.0004	1.2706	1.3840

Ratio of number of molecules of $PbSO_4$ to number of molecules of Fe_2O_3 to number of molecules of $BaSO_4$ is $PbSO_4 : Fe_2O_3 : BaSO_4 = 1 : 0.0076 : 1.08$ (theory $1 + (4 \times 0.0076)$, or 1.03).

Lead oxidixed, 13.06 per cent. Iron carried through, 0.05 per cent.

SPHALERITE WITH GALENA.

Experiment 13.—10 grams of each, 200 mesh; 10½ months; total solution 500 c.c.

	Solution, Grams
ZnO	0.0464
$PbSO_4$	0.0062
$BaSO_4$	0.1288

Zinc carried through, 0.56 per cent.

The lead sulphate remaining in the residue was not determined, so that the experiment is not completely comparable.

ENARGITE WITH PYRITE.

Experiment 14.—This is the same experiment quoted on page 31 of our previous paper. The enargite alone gave no copper, arsenic, nor iron, and only a trace of sulphur.

10 grams enargite and 10 grams pyrite; 4 months and 12 days; total solution 500 c.c.

	Solution, Grams.	Precipitate, Grams.	Total, Grams.
Cu_2S	0.2480	none	0.2480
Fe_2O_3	0.0165	0.0037	0.0202
$BaSO_4$	0.8310	none	0.8310
Arsenic	none	none	none

Ratio of number of molecules of Cu_2S to number of molecules of Fe_2O_3 to number of molecules of $BaSO_4$ is $Cu_2S : Fe_2O_3 : BaSO_4 = 1 : 0.081 : 2.29$ (theory, assuming that $Cu_2S \cdot \frac{1}{3}As_2S_5$ gives $Cu_2SO_4 + \frac{5}{3}H_2SO_4$, $2.66 + (4 \times 0.081)$, or 2.98).

PYRITE OR MARCASITE ABOVE SPHALERITE.

In the following experiments, a funnel containing pyrite or marcasite, prepared as previously described, was placed over a funnel containing sphalerite so that the washings from the pyrite or marcasite dripped upon and washed the sphalerite. The same minerals were used as in the above experiments.

Experiment 15.—10 grams pyrite and 10 grams sphalerite; total solution 375 c.c. Time 4 mo.

	Solution, Grams.	Precipitate, Grams.	Total, Grams.
ZnO	0.0094	——	0.0094
Fe_2O_3	0.0759	0.0023	0.0782
$BaSO_4$	0.2992	trace	0.2992

Ratio of number of molecules of ZnO to number of molecules of Fe_2O_3 to number of molecules of $BaSO_4$ is $ZnO : Fe_2O_3 : BaSO_4 = 0.235 : 1 : 2.62$ (theory, 4.235).

Zinc carried through, 0.11 per cent. Iron carried through 1.18 per cent.

Experiment 16.—Same as experiment 15; total solution 410 c.c.; no precipitate.

$$\begin{aligned} ZnO &= 0.0946 \text{ grams,} \\ Fe_2O_3 &= 0.1228 \text{ grams,} \\ BaSO_4 &= 0.6630 \text{ grams.} \end{aligned}$$

Ratio of number of molecules of ZnO to number of molecules of Fe_2O_3 to number of molecules of $BaSO_4$ is $ZnO : Fe_2O_3 : BaSO_4 = 1.51 : 1 : 3.69$ (theory, 5.51).

Zinc carried through, 1.13 per cent. Iron carried through, 1.85 per cent.

Experiment 17.—10 grams marcasite above 10 grams sphalerite; total solution 549 c.c.

$$\begin{aligned} ZnO &= 0.0888 \text{ grams,} \\ Fe_2O_3 &= 0.2339 \text{ grams,} \\ BaSO_4 &= 1.2270 \text{ grams.} \end{aligned}$$

Ratio of number of molecules of ZnO to number of molecules of Fe_2O_3 to number of molecules of $BaSO_4$ is $ZnO : Fe_2O_3 : BaSO_4 = 0.927 : 1 : 3.59$ (theory, 4.93).

Zinc carried through, 1.08 per cent. Iron carried through, 3.52 per cent.

Experiment 18.—In this experiment, another pyrite was used, for which the following figures are given when treated alone.

10 grams, through 100 mesh; 2 months and 18 days; total solution 1,033 c.c.

	Solution, Grams.	Precipitate, Grams.	Total, Grams.
Fe_2O_3	0.0594	0.0494	0.1088
$BaSO_4$	0.5247	0.0254	0.5501

Ratio of number of molecules of Fe_2O_3 to number of molecules of $BaSO_4$ is $Fe_2O_3 : BaSO_4 = 1 : 3.46$ (theory, $1 : 4$) = $Fe_2O_3/BaSO_4$.

Iron carried through, 1.64 per cent.

10 grams of this pyrite placed so that the washings from it dripped over 10 grams of sphalerite (also 100 mesh), for 2½ months, yielded 885 c.c. of a solution, which gave the following analysis:

	Solution, Grams.	Precipitate, Grams.	Total, Grams.
Fe_2O_3	0.0717	0.0195	0.0912
$ZnNH_4PO_4$	0.0779		

Ratio of number of molecules of $ZnNH_4PO_4$ to number of molecules of Fe_2O_3 to number of molecules of $BaSO_4$ is $ZnNH_4PO_4 : Fe_2O_3 : BaSO_4 = 0.76 : 1 : 1.95$ (theory, 4.76).

Zinc carried through, 0.43 per cent. Iron carried through, 1.37 per cent.

PYRITE WITH SILICA.

Experiment 19.—10 grams pyrite and 10 grams silica, finely divided and mixed, subjected to oxidation and moisture for 5 months and 11 days, gave 405 c.c. solution, containing the following:

	Grams.
Silica	0.0047
Ferrous sulphate	0.1734
Ferric sulphate	0.0109
Excess sulphur trioxide	0.0125

Ratio of number of molecules of Fe_2O_3 to number of molecules of SO_3 is $Fe_2O_3 : SO_3 = 1 : 5.59$ (theory, 1 : 4).

FeS_2 oxidized, 1.44 per cent.

DISCUSSION OF EXPERIMENTAL RESULTS.

The foregoing experiments confirm the results shown in our previous paper; namely, that there is a decided increase in the percentage of lead, zinc, and copper sulphides oxidized when these are mixed with the sulphides of iron. They also show that, in the case of such mixtures, the amount of iron transferred is but a small fraction of the amount transferred where the sulphides of iron are treated alone. Such mixtures evidently materially hinder the transfer of iron.

If solution of the various sulphides is due, as suggested by Allen and Wells, to the presence of the free sulphuric acid, there is no reason why the transfer of the iron should not proceed normally, and an equal amount be found in the solution derived from such mixtures.

Assuming that the iron sulphides oxidize according to equation No. 1, there is liberated one molecule of H_2SO_4 for each molecule of FeS_2 oxidized. The solution of a sulphide by this free sulphuric acid should take place according to the following equation: *e. g.,* sphalerite:

$$ZnS + H_2SO_4 = ZnSO_4 + H_2S.$$

There would be dissolved, in this case, approximately one molecule of ZnS to each molecule of FeS_2 oxidized, or about 0.8 as much by weight. If any free acid passes into the filtrate, the amount of zinc transferred would be correspondingly less. On the other hand, such solution should in no way effect the transfer of the iron other than abstracting the free H_2SO_4, thereby inhibiting, to some extent, the oxidation of ferrous sulphate to ferric sulphate. Such action would assist the transfer of iron by lessening the possibility of hydrolysis. As a matter of fact, the amount of zinc and lead oxidized is much greater than the amount specified above, and the amount of iron transferred is only a small part of that required by this theory. The absence of H_2S (as shown by experiment No. 3) indicates that if this gas is formed it must be wholly oxidized to sulphuric acid at once. This would hardly seem true in the case where ten pounds of marcasite were used and no air was forced through the mass.

One might assume, however, that as the FeS_2 is oxidized, virtually the entire amount of ferrous sulphate formed is oxidized at once to ferric sulphate, which hydrolizes instantly to ferric hydroxide and sulphuric acid and that the sulphuric acid dissolves the metallic sulphides before being washed into the flask below. This, however, requires a completed series of reactions that are hardly possible under the conditions. In experiment No. tion and hold the iron in the ferrous form, in which case it should

14, the cuprous copper of the enargite would prohibit such oxidabe washed through into the flask. This experiment, however, indicates that there was only a slight transfer of the iron, comparable in all respects with the transfer in the other experiments. Neither the copper nor the iron show any definite relation in the amounts transferred.

In the case of experiments 15, 16, 17, and 18, in which the marcasite and sphalerite were not in contact, the results indicate that in every case the iron carried through is greater than the zinc and that the zinc is much less than in the case of the two minerals being mixed. The oxidation of the zinc in these experiments was doubtless caused by the presence of iron salts, or the ZnS has been dissolved by H_2SO_4. They indicate, however, that the action of the iron sulphides is much more vigorous in the case of mixtures.

To retain the theory that the increased solubility of sphalerite or galena, when mixed with iron sulphides, is due to the free sulphuric acid, we must assume an almost complete hydrolysis of the ferrous sulphate solution after the free sulphuric acid is neutralized by the admixed sulphides. Such an assumption would be possible if the iron were present as ferric sulphate. This, however, is not the case, since in every instance the iron in solution is both ferric and ferrous, the latter usually in as large a proportion as the former. By comparing the experiments on galena and sphalerite, it is apparent that the hydrolysis would be greater in the presence of lead sulphide than in the presence of zinc sulphide, while actually a larger number of equivalents of the latter are carried through than of the former.

POSSIBLE ELECTROLYTIC ACTION.

It was these apparent inconsistencies with the demands of the solution theory that led to a consideration of the possible influence of electrolytic action, due to contact.

If there is a difference of potential between the sulphides in contact, and these sulphides are conductors, there should be created, by such contact, small batteries that would induce oxidation and

solution of the more negative mineral and protect or inhibit similar action on the positive mineral. This action would be analogous, in every respect, to the action of metals. It is well known that when two metals are placed in contact and moistened, one is oxidized in the air much more rapidly than it would be if alone, and that the other metal is almost completely shielded from oxidation, a fact used largely in a commercial way. It is found that the metal, forming the positive pole,[1] in a combination similar to an ordinary battery, is protected from change while the metal forming the negative pole is attacked more readily. This fact is most conveniently expressed by the electro-chemical series, in which the metals are arranged in such order that they progress from the more electro-negative to the more electro-positive. According to this order, any of the metals will cause those higher in the series to oxidize more rapidly when placed in contact and moistened and will itself be protected.

Thus zinc, iron, and tin occur in the electro-chemical series in the order named, starting with the most electro-negative. Iron, coated with zinc (galvanized iron) is protected not only because the zinc forms a thin film of insoluble oxide, but because the zinc protects the iron electrolytically as long as the film of moisture touches both metals. Iron, coated with tin (tin plate), is protected from rusting only so long as the tin coating is perfect, as even the minutest hole in the tin will, through electrolytic action, induce rusting of the iron beneath. In this case the iron will oxidize more rapidly than if alone.

These well-known facts of electro-chemistry are stated here in order to show the analogy in the case of two minerals in contact provided such minerals show a difference of potential and are conductors.

That many of the sulphides and oxides are comparatively good conductors is shown by the following table taken from Landolt-Boernstein-Meyerhoffer (values shown in reciprocal ohms):

[1] We regard an electrode as positive when it assumes a positive charge or gives a negative charge to the solution. See Whitney and Brown's edition of LeBlanc.

TABLE I.

Copper	600,000
Zinc	165,000
Nickel	105,000
Platinum	92,400
Mercury	10,444
Bismuth	9,190
Galena	8,470
Siberian graphite	820
Nickel ore	313
Electric light carbon	300
Pyrrhotite	119
Chalcocite	91.0
Ferrous sulphide	8.98
Hematite	2.41
Magnetite	1.68
Chalcopyrite	0.983
Pyrite	0.661
Stannous sulphide	0.000935
Siderite	0.000140
Distilled water	0.00001
Glass	0.0000000000000202
Hard rubber	0.00000000000000486
Mica	0.000000000000000114

Many of the sulphides, as shown, are similar to the metals in conductivity and will readily act as efficient electrodes.

The authors were unable to find figures showing the difference of potential shown by the various natural sulphides and oxides. Measurements made with an Ostwald potentiometer and a Lippman capillary electrometer, indicate that there is a decided difference in potential between the minerals when placed in contact and moistened, and the minerals can be arranged in a series similar to the electro-chemical series.

The following table is a selection of measurements made with distilled water. For convenience, the various minerals were measured against copper wire; the "+" or "—" sign indicates the charge assumed by the minerals. The figures are given in volts.

TABLE II.

Marcasite$^+$	0.37	Chalcocite$^+$	0.14
Argentite$^+$	0.27	Hematite$^+$	0.08 to 0.26
Cassiterite$^+$	0.27	Cuprite$^+$	0.05
Chalcopyrite$^+$	0.18 to 0.30	Niccolite$^+$	0.02
Enargite$^+$	0.18 to 0.23	Domeykite$^+$	0.01
Molybdenite$^+$	0.20	Metallic copper	0.00
Covellite$^+$	0.20	Stibnite$^-$	0.17 to 0.6
Pyrite$^+$	0.18	Sphalerite$^-$	0.2 to 0.4
Bornite$^+$	0.17	Corundum$^-$	0.25 to 0.6
Mixed copper ore$^+$	0.15	Metallic zinc$^-$	0.83
Galena$^+$	0.15		

According to this table, marcasite shows the highest E.M.F., while corundum shows the lowest for the minerals, the difference being more than 0.6 of a volt. Metallic zinc shows a negative voltage to copper of 0.83 of a volt, there being a difference between the highest and lowest member of the series of 1.2 volts.

Since, as already shown in Table I., many of the natural minerals are good conductors, this difference in voltage should, where two minerals are in contact and moistened, form a small battery in which the current will flow out of the solution from the mineral having the highest potential. By such action the mineral lowest in the series would dissolve more rapidly, while the one higher in the series would be protected from oxidation.

In order to test the truth of the above assumption, a number of experiments have been carried out, as follows:

Experiment 20.—Pieces of pyrite and galena, two inches in length and approximately one inch square, having copper wire attached near one end, were placed in a small dish containing ordinary distilled water; the wire did not touch the water, nor were the minerals in contact. Upon short-circuiting, through a galvanometer, the same electro-motive force was obtained as shown in the above table, and a current of about 5 microamperes was recorded. In the course of a few days the galena became coated with lead sulphate, while a similar piece of galena, placed in the same solution, but not short-circuited, remains perfectly bright. There is no action on the pyrite.

Replacing the galena with sphalerite, the electro-motive force is much greater, as shown by the table, while the current, on short circuiting, is at least ten times as great but drops to nearly zero in a few seconds. If the sphalerite electrode is removed, the surface cleansed with a dry cloth, and replaced in the circuit, it gives the original value with the same rapid drop of the electro-motive force.

According to this action, pyrite and marcasite, when in contact with galena and sphalerite, are prevented from oxidation, while the latter minerals are dissolved with greater rapidity. This has been shown to be the case all through our experimental work.

If the conception that such contact action protects the sulphides higher in the series, certain of them, occurring near the middle of the series, should exert an accelerating action on those minerals above it in the series, and a protective action on those below, while metallic copper and metallic zinc should retard the oxidation of most of the minerals of the series.

In order to test this fact, the following series of experiments was carried out.

Experiment 21.—Five funnels and flasks were prepared in the usual way. The following metals and mixtures were placed upon these filters, and washed twice daily with distilled water for one and one half months:

Exp. 1. Marcasite, 20 grams, through 80 mesh and on 120 mesh,
Exp. 2. Metallic zinc, C. P., 40 grams of 30 mesh,
Exp. 3. Metallic copper (finely precipitated from solution by zinc), 25 grams,
Exp. 4. Mixture of { Marcasite, 20 grams, Metallic copper, 25 grams.
Exp. 5. Mixture of { Marcasite, 20 grams, Metallic zinc, 40 grams,

During the washing, the metallic copper, both alone and in admixture, became dark in color, indicating that it had changed in part to the oxide. The metallic zinc, in both cases, shows oxidation to the oxide of zinc, which is perceptible, due to its very white color. The marcasite alone oxidized in the normal way, showing hydrolysis in the flask and iron salts along the rim of the funnel.

Table No. 3 shows the results of these experiments; amounts given in grams; solutions approximately 500 c.c. in each case.

TABLE III.

No.	Substances.	Fe_2O_3.	Cu.	Zn.	S.
1	Marcasite	0.1495	——	——	0.158
2	Zinc, metallic	——	——	none	——
3	Copper, metallic	——	none	——	——
4	Marcasite, zinc, metallic	none	——	none	none
5	Marcasite, copper, metallic	none	none	——	none

Only in the case of marcasite, alone, has there been any transfer of iron or sulphur. The presence of the copper and zinc has completely prevented even the slightest oxidation of the marcasite. Had there been any oxidation of the marcasite, the sulphuric acid formed would have readily dissolved the copper or zinc, which would have been washed through, into the flask, as zinc or copper sulphates.

In a series of incomplete experiments, ullmannite ($NiS_2 \cdot NiSb_2$) is being treated alone, and in mixtures with other minerals, including hematite, molybdenite, sphalerite, franklinite, stibnite, and crystallized stannous sulphide, respectively. Time of treatment two months.

From the depth of the nickel-green color of the solutions, and from the amount of greenish salt on the sides of the funnels, it is apparent that the greatest amount of oxidation is being obtained with the hematite-ullmannite mixture. The mixtures with molybdenite and with stannous sulphide show marked action, and the mixtures with franklinite and with sphalerite have slightly greenish filtrates. Alone, or with stibnite, the amount of nickel in solution is too small to be detected by the eye. Hematite apparently has a decided accelerating effect in this case, while franklinite, which is also an oxide, apparently has the same effect to a lesser degree. This series of experiments indicates that contact action with oxides may produce the same results as in the case of the sulphides.

A number of experiments are now being carried on to deter-

mine still further the protective or accelerating action of minerals other than the di-sulphides. The number of possibilities which can be predicted from the table of electro-motive force measurements will give us crucial experiments upon which to test the limits of such action.

SUMMARY.

In this paper we have (1) confirmed our observations on the increased solubility of sulphides, in the presence of marcasite or pyrite; (2) shown that there is a complementary protection from oxidation of the pyrite or marcasite; (3) shown that there exists a difference of electro-motive force between the various natural minerals and arranged a number of these in a series analogous to the electro-chemical series of the metals; (4) shown that the minerals, when in contact and moistened, act as batteries; (5) indicated that such contact may be an important factor in the general process of oxidation of the natural minerals.

A majority of the above analyses were made by Mr. A. X. Illinski, chemist to the Bureau of Geology and Mines.

CONDITIONS OF MINERALIZATION IN THE COPPER VEINS AT BUTTE, MONTANA.

CHARLES T. KIRK.

INTRODUCTION.

Since the discovery of copper ore at Butte in 1882 successive studies of the mineralization of that district have shown many unexpected features. These have puzzled the geologist and therefore rendered more or less speculative the immense investment of the capitalist. Yet during the rapidly increasing production from the various copper deposits of the world, that at Butte has held first place since 1887. To the end of 1909 the recorded production of copper from this district closely approximated 5,000,000,000 pounds, representing as marketed gross returns of 665,000,000 dollars. From two square miles of area there are now being hoisted annually some 4,000,000 tons of ore, from which are recovered gross market values of 40,000,000 dollars in copper, 5,000,000 in silver, and 1,000,000 in gold, with minor returns in lead and zinc. The immensity of the deposits, however, can hardly be of greater interest to the economic geologist than their manner of origin.

Some two years ago the writer made quantitative investigations of certain of these deposits, undertaking to correlate alterations of country rock with primary mineralization and subsequent enrichment of copper veins. During those investigations field observations were compared not only with petrographic studies of wall rocks and ores, but these checked closely with careful interpretations of quantitative chemical analyses of rocks, ores, and mine waters. In this paper the petrographic phases are presented, with only such reference to chemical considerations as seem indispensable; the chemical conditions will be discussed at length in a later paper by W. J. Mead.

The data and observations for the present paper were obtained

mainly from regions below the oxidized zone, most of them from the Pittsmont mine, in the southeastern portion of the copper district. The workings of this property underlie a considerable thickness of valley drift, below which is a zone of variable depth of oxidized country rock in place. Immediately under this is the characteristic[1] sharp contact with the sulphide zone. With the exception of the minor surface peculiarities mentioned, the writer has observed that the nature of the country rock and its manner of mineralization are similar to those elsewhere in the district. The value of the results has been much enhanced by the interest and criticism of professors C. K. Leith, Alexander N. Winchell, and W. J Mead, and especially by frequent reference to the excellent body of chemical data collected by Professor Mead.

ESSENTIAL GEOLOGIC FEATURES.

Since the present study has to do with special conditions, the general geologic features are here given only brief discussion; their comprehensive treatment appears in various general works[2] on the region.

The country rock, known as the Butte granite, is a quartz monzonite of Tertiary age. It has a composition slightly more basic than the prevailing type rock of the Boulder batholith,[3] of which it forms several square miles of the southern interior. Since the beginning of solidification of the granite there have been no less than three periods of igneous activity. The products of these in the order of their ages are: Bluebird granite, an aplite, sometimes called alaskite; Modoc porphyry, a quartz porphyry with fine grained ground mass; rhyolite, distinguished easily from Modoc porphyry by its small specks of biotite. All these are of more acidic nature than the Butte granite, and all occur as dikes,

[1] Sales, ECON. GEOL., V., 1910, p. 19; Wetzig, *Zeitsch. f. prak. Geol.*, XIV., 1906, p. 180.

[2] Weed, Folio 38, U. S. Geol. Survey, 1897; *Jour. Geol.*, VII., 1899, pp. 737–750; 21st Ann. Rep., U. S. Geol. Survey, II., 1900, pp. 227–255; Bull. 213, U. S. Geol. Survey, 1903, pp. 170–180; "Copper Mines of the World," New York, 1908, pp. 320–334; Barrell, 22d Ann. Rep., U. S. Geol. Survey, II., 1901, pp. 511–549.

[3] Barrell, *loc. cit.*, p. 535. Also p. 811, v, below.

though the rhyolite appears also as a volcanic neck, the "Big Butte," from which several flows radiate.

The granite of the district proper has been further disturbed by at least three sets of vertical, intersecting faults, the oldest striking east-west, the second northwest, the youngest northeast. This order of age is also that of importance in content of copper, the oldest being most productive. The periods of vulcanism just mentioned are definitely related chronologically with the faults, or veins. The aplite is more or less common in the copper district, and is older than the oldest system of faults; the Modoc porphyry is especially characteristic of the producing mines, and is cut by all the fault systems; the rhyolite dikes and flows lie rather to the west of the copper veins, and have been found to be later than the veins. Thus intrusive action has preceded, and volcanic action followed faulting.

Perhaps the most remarkable structural feature of the district is the Continental Fault nearly two miles east of middle Butte. Its scarp of some 2,000 feet shades directly away from the continental divide, Butte being on the downthrown side. Its time relation to the copper-bearing veins has not been definitely determined, to the writer's knowledge, but it is believed to be younger[1] than the copper veins, and may therefore have caused important readjustments of the water table since the first mineralization of the veins. Besides calling attention to the suggestive appearance of this feature, Weed states that certain changes in the drainage systems of the immediate region warrant the conclusion that the divide is here due to faulting. Emmons's statement that the fault "must have occurred in comparatively recent times" is well borne out by the steepness and ruggedness of the scarp as contrasted with the more subdued topography immediately surrounding Butte. Sales's paper,[2] describes the ore of the Bullwhacker mine, occurring along the Continental Fault, as "a typical Butte granite, stained and enriched by the copper silicate chrysocolla." Since presumably no pyritization has occurred here, an action evident in all but the latest faults of the

[1] S. F. Emmons, "Gen. Ore Dep.," trans., New York, 2d ed., 1902, pp. 444–445.
[2] *Ibid.*, p. 20.

Butte district it seems further probable that the fault occurred since the mineralization of the copper veins.

No hot liquid nor gaseous emanations are observed at present in the Butte district, though hot springs exist in this batholith, and deep seated occurrences of rhodochrosite and fluorite exist as fossil emanations[1] of carbon dioxide and fluorite. Besides the hot springs at Boulder, 25 miles northeast of Butte, those at Pipestone, 20 miles east, at Gregson, 15 miles west, and Crystal Springs, 6 miles west are conspicuous examples. The nature of the alterations accomplished by the waters at Boulder has been investigated by Weed[2] and Lindgren; in the other cases mentioned the immediate effects of hydrothermal action are not exposed.

FRESH AND ALTERATION PHASES OF BUTTE GRANITE.

Fresh Granite; General Relations to Altered Phases in Sulphide Zone.—There is probably no unaltered Butte granite in the copper-bearing area of the Butte district. Even well without the district, where the light-colored constituents are not stained to the typical drab color characteristic of the "mineralized" granite, and where pyrite exists in the minutest traces in the ferro-magnesian minerals, chlorite and sometimes sericite are present. It is generally possible below the oxidized zone to collect a suite of specimens illustrating a complete lateral gradation from this original, unmineralized granite to the dense-textured, highly-sericitized, pyritized, siliceous alteration product adjoining the veins. This series may be easily and convenienty classified into three facies: (1) the fresh, (2) the chloritized, and (3) the sericitized—in the order of their general gradation toward the veins. When considered in the reverse order, that is, from the veins outward, these vertically-standing zones of alteration show more or less symmetrical arrangement with respect to the veins. The width of these zones may usually be measured in tens of feet, though occasionally they extend over more than a hundred feet.

[1] Lincoln, Econ. Geol., II., 1907, pp. 259, 268; Clarke, U. S. Bull. 330, 1908, 274, 490. Page 490 makes only a very general reference to the association of rhodochrosite.

[2] U. S. Geol. Survey, 21st Ann. Rep., II., 227–255.

While the alteration grading from fresh granite toward the veins is to be observed, as just pointed out, it is by no means ideal. The broken country rock is generally altered both in direct proportion to the intensity of shattering and proximity of veins, the larger and especially the older veins accompanying the more intense phases. Since the irregular fracturing of the country rock has produced numerous minor zones of shattering about areas of relatively solid granite—the latter often fives and tens of feet across—discrimination must therefore be used in selecting a series to represent an alteration grading over a given distance. Chlorite in the Butte granite rarely exceeds 5 per cent. of the volume, yet on the other hand it is seldom entirely absent from a hand specimen of even the most highly sericitic phase. The chloritic phase will be understood to indicate between 1 and 5 per cent. of chlorite, with perhaps equal weights of pyrite. Attendant conditions are discussed below.

It is evident to the unaided eye that chlorite and sericite are associated in the slightest alterations in the sulphide zone, yet as shown below, while chlorite is more obvious than sericite in the slightly altered granite, chlorite appears in only microscopic traces in the extremely sericitic phases.

Fresh Granite; Physical Features.—The essential characteristics of the fresh facies as studied in the field and laboratory may be rather closely approximated in a macroscopic description.

The writer has examined rather large exposures of extremely fresh, firm granite near Homestake, 10 miles east of Butte, on the Northern Pacific Railway, and on Timbered Butte, two miles south of the main producing mines. The Homestake variety contains fewer ferric minerals and is therefore lighter in color than the typical Butte granite. Either Homestake or Timbered Butte is the locality of the building stone of which a petrographic analysis exists.[1]

Apparently nearly 20 per cent. of the volume of the typical Butte granite is made up of the dark magnesian and iron minerals, biotite, hornblende, augite, and magnetite, decreasing in

[1] "Quant. Class. Ign. Rocks," Cross, et al., p. 226.

abundance in the order named. Pyrite exists in isolated specks, not amounting to 0.05 per cent. volume in Weed's average analysis, which includes rocks within the producing or "mineralized" district. The pyrite is more abundant, however, in and around the basic inclusions in the granite. The light-colored components visible under the lens comprise almost 60 per cent. of feldspar, which is plagioclase and orthoclase in respective proportions of slightly more than 2 to 1, and nearly 25 per cent. of quartz. The average density determined by experiment is 2.74, which checks with densities as computed from mineral analyses. The porosity is slightly lower than 1 per cent., as determined[1] carefully from various samples.

Microscopic study proves the accuracy of the approximate proportions given above. In addition to the minerals mentioned, apatite is thus revealed. It is more abundant in the quartz and orthoclase areas, but many inclusions exist in the plagioclase. Liquid inclusions with bubbles are confined to the primary quartz. Traces of pyrite are to be seen especially near certain basic inclusions, but no recognizable copper-bearing minerals.[2] No rutile was seen in these fresh samples, yet occasional grains of titanite were identified. None of the sections examined was absolutely free from sericite, nor, on the other hand, from kaolin. The pyroxenes and hornblende were found to be slightly altered, traces of chlorite being associated with them.

Fresh Granite; Chemical Features.—The complete chemical analysis of a fresh sample from Walkerville, north of the central copper mines, is published by Weed,[3] as given herewith, page 41, I., and has been discussed in a private publication.[4]

[1] For methods employed see paper by W. J. Mead on the relation of density, porosity, and moisture to the specific volumes of ores, ECON. GEOL., III., pp. 319–325.

[2] Kemp, ECON. GEOL., I., 1905, pp. 207–232, especially pages 225, et seq. Kemp here shows quantitatively that the probabilities of the leaching, in nature, of traces of metals from a rock of little porosity, are extremely low.

[3] *Jour. Geol.*, VII., 1899, p. 739, No. 623; also Bull. U. S. Geol. Surv. 419, 1910, p. 77, *A*.

[4] Cross, et al., *loc. cit.*, pp. 223 et seq.

TABLE SHOWING COMPLETE CHEMICAL ANALYSES OF GRANITE FROM BOULDER BATHOLITH.

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2.....	63.88	64.34	62.36	64.03	67.12	68.54	63.73
Al_2O_3....	15.84	15.72	15.68	15.58	15.00	14.43	13.67
Fe_2O_3 ...	2.11	1.62	1.93	1.98	1.62	2.03	6.31
FeO.....	2.59	2.94	2.81	2.83	2.23	1.75	2.13
MgO	2.13	2.17	2.17	2.15	1.74	1.76	2.43
CaO.....	3.97	4.24	4.27	4.20	3.43	3.58	2.80
Na_2O....	2.81	2.76	2.59	2.76	2.76	2.18	2.04
K_2O.....	4.23	4.04	4.44	4.11	4.52	4.47	5.36
H_2O-...	.22	.25	.85	.23	.09	.07	.31
H_2O+...	.66	.76	1.09	.73	.58	.64	1.01
TiO_2.....	.65	.53	.78	———	.48	.42	.27
ZrO_2.....	———	.02	———	.60	———	———	———
CO_2	———	.03	.29	.13	.00	———	———
P_2O_5.....	.21	.14	.15	.18	.15	———	tr
MnO....	.07	.12	.08	.11	.06	———	.10
BaO.....	.09	.06	.04	.07	.07	———	.00
SrO	.02	.03	———	.04	.03	———	.00
FeS_2.....	tr	.03	.56	.06	tr?	tr	.05
Cu.....	———	.005	.04	.005	———	.00	———
Total..	99.82	99.805	100.14	99.75	99.88	99.87	100.28

I. Weed's sample from Walkerville, about one mile north of central copper area. Shows also traces of lithia and chlorine, and 0.34 of SO_3.

II. Weed's type sample of Butte granite, Atlantic mine. Compares closely with IV., this series.

III. Freshest granite sampled in Pittsmont. Collected a few hundred feet from II., and in similar country. Analysis by N. N. Blye, chief chemist, East Butte Copper Mining Co.

IV. Average of Weed's Butte granites; four analyses. *A, B* (here given as I. and II.), *C*, and *D*, in Bull. U. S. Geol. Survey, 419, 1910, p. 77.

V. Prevailing type of granite for batholith; Boulder, Mont., *loc. cit.*, p. 19, *B*.

VI. Granite from Homestake, Mont., ten miles southeast of Butte. Analysis by the writer, 1909.

VII. Granite from Timbered Butte, two miles south of larger group of copper mines. From unpub. MS. on the estimation of the quantitative mineral composition of granular igneous rocks, by F. C. Lincoln and L. J. Hartzell. Contrast contents of Fe_2O_3 and Al_2O_3 in I. and VII.

It is important to notice that in the typical Butte granite, II., titania and water are well below 1 per cent., ferric oxide is almost 2 per cent., and the remaining basic oxides, ferrous iron, magnesia, soda, and potassa are each above 2 per cent. Special notice is directed to the lower content of potassa (4.15) than of lime (4.34) in this phase; indeed the proportions of potassa to

all other bases during the various alterations of this rock are deemed of the utmost importance and will receive careful consideration. It must be said of the average analysis submitted, IV., that its contents of pyrite and copper, the latter computed for convenience as chalcocite are almost certainly higher than would be true for any unaltered sample. Three of the analyses[1] used for this average were made from samples taken in the producing area, and however fresh-appearing, had probably been exposed to mineralization; the content of SO_3 in the remaining one, I. as here given, indicates suspicious association for it also. Weed's average corresponds extremely closely with his sample from the Atlantic mine, and shows but little less alteration than is indicated by the minute increments of water, pyrite, and copper in III., an analysis of a sample taken in the northern workings of the Pittsmont mine, only a few hundred feet from the Atlantic. The well marked migration of materials as seen under the microscope in this rock is not indicated by the chemical analysis.

The accompanying chemical analyses show then that the Butte granite is of basic affinity, and while otherwise slightly variant in chemical and mineralogical nature, contains nowhere more than appreciable quantities of metallic sulphides. It is so easily altered and replaced that fresh samples can scarcely be obtained in the vicinity of the copper district even at localities not considered to have been exposed to any sort of alteration, yet the earlier alterations involve little change in the essential chemical components.

Chloritic Phase; Physical Features.—Grading laterally from the fresh granite is a chloritized facies having many characteristics analogous to those of propylitized rocks. These chloritic areas lie well within the copper district but are not closely associated with the veins. This phase is easily detected in unoxidized specimens by relative scarcity of dark, femic constituents, many of which have been altered to grayish green chlorite now remaining in flakes visible to the eye. There is usually pyrite present though in somewhat less volume than chlorite. In phys-

[1] Bull. U. S. Geol. Survey, 419, p. 77, *D*, *E*, and *F*.

ical appearance this chloritized rock is apparently of as firm texture as the original granite. Its specific gravity has increased nearly 5 per cent. Since porosity still remains below 1 per cent., volume may fairly be assumed to have remained constant.

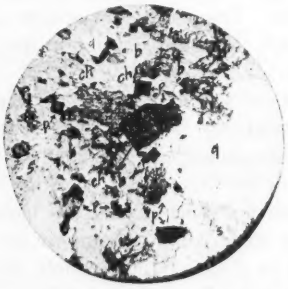

FIG. 440. Photomicrograph showing the formation of abundant epidote, pyrite, and chlorite in a crystal of biotite. × 35. One nicol. q = quartz; q_2 = secondary quartz; Or = orthoclase; Lb = labradorite; b = biotite; Hb = hornblende; a = apatite; p = pyrite; M = magnetite; s = sericite, ch = chlorite; e = epidote; Sf = sericite replacing feldspar; t = titanite.

Under the microscope this phase is much more markedly different from the fresh granite than appears under the lens. Excepting perhaps quartz, none of the essential constituents is unaltered. Unless the rock is almost entirely fresh, augite is difficult to identify; hornblende also is decomposed early in the process. In the traces of these minerals there appear chlorite, pyrite, epidote, secondary quartz, and, doubtfully, minute traces of carbonates, with more or less sericite. Contemporaneous with the alterations detected in the augite and hornblende, similar changes evidently occur in the biotite, excepting that in this instance less epidote was observed, and rods and meshes of rutile are not uncommon. Careful examination for primary rutile has failed to reveal any traces either in the femic minerals or elsewhere in the fresh Butte granite. While the augite and hornblende are first to submit to alteration, this does not appear to be because of their relatively small occurrence, since tiny shreds

of biotite withstand the actions that have almost decomposed adjacent hornblende crystals. Perhaps the most striking feature of the chloritic alteration is the close association of that pyrite not formed in fissures to the traces of former ferro-magnesian minerals. Not uncommonly this pyrite is surrounded by a rim of secondary silica. The pyrite may possess well-defined crystal faces, which do not commonly develop in the sericitic alteration phase discussed beyond.

The occurrences of sericite in the chloritic phase are not confined to the chloritizing crystals, though evidently these are easily altered to fibrous, sericitic, rutilated masses. While chlorite is evidently in the process of formation labradorite begins to give place to sericite, which replaces the labradorite with characteristic ease, as noted below. Some of the orthoclase is replaced by sericite in the meantime, mainly along cleavages and fissures, yet during the formation of chlorite, the sericitization of the feldspars is of less importance than afterwards.

Chloritic Phase; Chemical Features.—The mineral alteration occurring during these replacements require certain chemical readjustments. The passage of augite and hornblende to chlorite and epidote requires the addition of water and the separation of silica. The reaction may occur thus:

$$\underset{\text{Augite or hornblende}}{8CaMg_2FeSi_4O_{12}\cdot 2Mg_4Fe_2Al_8Fe_4Si_6O_{36}} + \underset{\text{Water}}{21H_2O} + \underset{\text{Carbon dioxide}}{16CO_2} =$$

$$= \underset{\text{Chlorite}}{2(H_{20}Mg_{12}Al_6Si_7O_{45})} + \underset{\text{Epidote}}{2HCa_2Al_2FeSi_3O_{13}} + \underset{\text{Calcite}}{4CaOCO_2}$$

$$+ \underset{\text{Siderite}}{12FeOCO_2} + \underset{\text{Silica}}{24SiO_2} + \underset{\text{Iron oxide.}}{3Fe_2O_3}.$$

It has been doubted that sulphuric anhydride may be substituted for the carbon dioxide with similar results, though the presence of sulphates in the hot spring waters at Boulder lend a probability to such action. Reduction of the iron oxides of the primary minerals, as discussed below, would furnish oxygen for the formation of the anhydride, the probable presence of which must be considered in discussing the ore deposition.

The substitution of chlorite and epidote for biotite requires gain of lime and water, and loss of potassa. At the same time the labradorite is observed to give place to sericite, which action means loss of lime and gain of potassa. Thus the interactions seem complementary and typical equations may be set thus:

$$\underset{\text{Biotite}}{60KHMg_2Al_2Si_3O_{12}} + \underset{\text{Iron oxide}}{6Fe_2O_3} + \underset{\text{Calcite}}{40CaOCO_2} + \underset{\text{Water}}{76H_2O} =$$

$$= \underset{\text{Biotite-chlorite}}{30(H_2Mg_4Al_2Si_3O_{12}\cdot 4(OH))} + \underset{\text{Epidote}}{4H_5Ca_{10}Al_{12}Fe_3Si_{15}O_{65}}$$

$$+ \underset{\text{Silica}}{30SiO_2} + \underset{\text{Diaspore}}{12AlO(OH)} + \underset{\text{Potassium carbonate}}{30K_2OCO_2} + \underset{\text{Carbon dioxide.}}{10CO_2},$$

and

$$\underset{\text{Anorthite}}{3CaAl_2Si_2O_8} + \underset{\text{Potassium carbonate}}{K_2OCO_2} + \underset{\text{Water}}{2H_2O} + \underset{\text{Carbon dioxide}}{2CO_2}$$

$$= \underset{\text{Sericite}}{2KH_2Al_3(SiO_4)_3} + \underset{\text{Calcite.}}{3CaOCO_2}.$$

Since no diaspore could be recognized in the localities typified by the first of these three equations, it is probable that it combined with the orthoclase to form sericite, thus:

$$\underset{\text{Orthoclase}}{KAlSi_3O_8} + \underset{\text{Diaspore}}{2AlO(OH)} = \underset{\text{Sericite.}}{KH_2Al_3(SiO_4)_3}$$

Although the biotite may supply the potassa, yet since orthoclase is present in the rock, the following may occur:

$$\underset{\text{Anorthite}}{CaAl_2Si_2O_8} + \underset{\text{Orthoclase}}{KAlSi_3O_8} + \underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Water}}{H_2O}$$

$$= \underset{\text{Sericite}}{KH_2Al_3(SiO_4)_3} + \underset{\text{Calcite}}{CaOCO_2} + \underset{\text{Silica.}}{2SiO_2}.$$

For the sake of completeness it seems well to note here rather than later the probability of replacement of orthoclase in situ as follows:

Orthoclase + Water + Carbon dioxide = Sericite

$$3KAlSi_3O_8 + H_2O + CO_2 = KH_2Al_3(SiO_4)_3 .$$

Potassium carbonate + Silica.

$$+ K_2OCO_2 + 6SiO_2.$$

Also

Orthoclase + Water = Sericite + Potassium silicate + Silica.

$$3KAlSi_3O_8 + H_2O = KH_2Al_3(SiO_4)_3 + K_2SiO_3 + 5SiO_2.$$

The iron sesquioxide required for alteration of the biotite may become available by the reaction submitted above for alteration of the pyroxene and amphibole.

The local migrations of bases during this phase of alteration probably occur in solution either as bicarbonates or hydroxides; at all events the former is a common constituent of hot spring waters. The presence of an epidote of low birefringence and low content of iron, thus resembling zoisite, indicates the probability of Clarke's reaction,[1] which predicts the "transformation of plagioclase into a mixture of zoisite, paragonite and quartz," though it was impossible to prove paragonite, even by mineral computations.

Pyritization of Iron-bearing Minerals.—The occurrence of much pyrite in the traces of former ferro-magnesian areas has already been mentioned. This phenomenon of pyritization of the iron in silicates[2] and oxides[3] has received description for other localities, but the relations here are so suggestive as to invite estimations of the relative amounts of iron in the primary minerals and the pyrite. Weed's analyses of hornblende and biotite from the Butte granite show 11.47 per cent. metallic iron in the former and 14.34 per cent. in the latter.[4] These quantities of iron would form with the necessary sulphur 24.60 and 30.75 per

[1] Bull. U. S. Geol. Surv. 330, 1908, p. 513.

[2] Becker, "Geol. of the Comstock Lode," Mon. U. S. Geol. Surv., III., 1882, pp. 210 and 211.

[3] A. N. Winchell, *Amer. Geol.*, Vol. 26, 1900, p. 184.

[4] Computed from oxides in analyses, Bull. U. S. Geol. Surv., 419, 1910, p. 77.

cent. of pyrite by weight respectively. Considering relative gravities, the volumes of the pyrite would be 15.30 per cent. of the hornblende and 18.20 per cent. of the biotite.

Various micrometric estimations of the volumes of pyrite in the traces of the ferro-magnesian minerals show that the pyrite comprises from 10 per cent. to approximately 14 per cent. (fig. 441) of their volumes. Thus it seems possible that the femic minerals could have supplied enough iron in situ for the formation of the observed pyrite, with some iron in excess. It may be added that, since the total iron in the average analysis of the fresh granite shows only 2.45 per cent., and the average of the sericitic rock filling the same volume shows 5.41 per cent., the iron of the original granite cannot have been sufficient to form all the pyrite of the final pyritized rock, not to mention that pyrite within the veins.

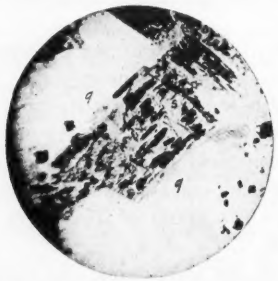

FIG. 441. Photomicrograph showing pyrite developing in a crystal of biotite. × 25. One nicol. q = quartz; q_2 = secondary quartz; *Or* = orthoclase; *Lb* = labradorite; b = biotite; *Hb* = hornblende; a = apatite; p = pyrite; M = magnetite; s = sericite; *ch* = chlorite; e = epidote; *Sf* = sericite replacing feldspar; t = titanite.

The instructive experiments of de Senarmont[1] are of interest in this connection. He heated iron salts with carbon dioxide, sulphuretted hydrogen, and alkaline sulphides, alone and in various proportions, in sealed glass tubes at temperatures ranging from

[1] *Comp. Rend.*, 32, pp. 409–413.

100° C. to 350° C., and obtained pyrite. At the writer's instance M. E. Diemer has prepared an aqueous solution of sulphuretted hydrogen in which about two grams of non-pyritous femic minerals separated from the granite of Timbered Butte was digested for 12 hours at above 150° C. in a sealed glass tube, the temperature being approximately 170° C. for the last 6 hours. The resulting solution was basic in reaction, and its filtrate gave a gelatinous silica test, indicating decomposition of the silicates. The writer afterwards ran a hydrogen sulphide solution under similar conditions for 3 hours in another section of this tubing without content of femic minerals, but was unable to get either a basic reaction or a test for silica. Decomposition of the ferro-magnesian separate and not of the glass tube was thereby assured, and though the experiment was not repeated with water alone, in order to test the efficacy of that body under such conditions, it seems probable that the hydrogen sulphide was the active decomposing agent.[1]

The digested ferro-magnesian minerals were carefully tested by Diemer for presence of pyritous sulphur. The possible non-pyritous sulphur was separated by water and by HCl, and the residue treated with aqua regia; the pyritous sulphur thus oxidized was then precipitated as $BaSO_4$. On ignition the precipitate weighed .024 grams, corresponding to .0062 grams of pyrite from approximately two grams of silicates, or about 0.0031 per cent. of pyritization.

Other portions of the ferro-magnesian minerals were boiled in 10 per cent. caustic soda solution and in sodium carbonate solution of similar strength for 10 hours and 6 hours respectively. Both treatments resulted in abundant gelatinous silica upon qualitative tests, showing decomposition by such reagents at ordinary pressure.

The conditions of these experiments are believed to be sufficiently analogous to those present during pyritization—and chlori-

[1] "Chem. and Phys. Geol.," English trans. by Paul and Drummond, Vol. I., 1854, p. 335. Bischof here discusses Sainte-Claire Deville's paper, *Compt. Rend.*, Vol. 35, p. 261, which shows decomposition of silicate rock by vapors impregnated with sulphuretted hydrogen.

tization and sericitization—at Butte to warrant the statement that the ferrous silicates and perhaps the magnetite could have been decomposed by hydrogen sulphide, alkaline sulphides or carbonates, or possibly by caustic alkalies, and the iron converted simultaneously into pyrite by the sulphides mentioned, or by fumarolic or solfataric action.

From the fact that the writer has seen no marcasite nor pyrrhotite from the Butte district, nor any report of such occurrences there, he infers that the sulphidation has taken place either in very alkaline environment or at temperatures above 400° C., and possibly under both conditions, else marcasite would have resulted; and not above 575° C., else pyrrhotite would have formed.[1]

Sulphidation of iron has been accomplished experimentally by MM. Pipervaut and Vila,[2] who have decomposed oxides of various metals with caustic alkalies and produced their sulphides by means of nascent alkali sulphides, merely by prolonged boiling under atmospheric conditions with repeated additions of powdered sulphur in small amounts. It is believed that decomposition by alkali carbonates would have been as effective, though slower.

Summary of Chloritic Processes.—In recounting briefly the main points in the chloritic stage of alteration, it must be noticed first of all that the ferro-magnesian minerals are easily replaced. In so far as their replacement by chlorite and epidote is concerned, there is probably merely a recombination of the bases lime and potassa. Possibly sufficient lime may be furnished by the hornblende, yet there is a greater possibility that portions of this base would come from the more abundant labradorite, especially since this is giving place to appreciable amounts of sericite. The development of chlorite and sericite requires the addition of combined water and the local separation of silica. The formation of chlorite here explains the relative retention of magnesia, which appears to emigrate at this stage only slightly faster than

[1] "Studies in Ore Deposition with Special Reference to the Sulphides of Iron," E. T. Allen, *Jour. Wash. Acad. Sci.*, I., 170–177, 1911.

[2] *Bull. Soc. d'Encouragement pour l'Industrie National*, II., 1909, pp. 522, 523.

potassa. Accompanying this chloritization, especially of the biotite, there is frequently a separation of rutile.

It is well known that chlorite, epidote, and rutile occur commonly in schists, rocks which are developed under high pressure.[1] Chlorite, moreover, is formed by hydrothermal action[2] in igneous rocks, while epidote is found typically at igneous contacts,[3] and may therefore be considered a high temperature mineral. Certain syntheses[4] of crystalline titanium dioxide go to show that rutile forms at a higher temperature than either anatase or brookite, or above the boiling point of zinc[5] (930° C.). Doelter[6] has dissolved rutile in water and in sodium fluoride solution and reproduced crystals of rutile from the latter by digestion at 145° C. in a glass tube (pressure not given) for a period of 34 days, showing that under pneumatolytic conditions probably analogous to those accompanying chloritization at Butte, the mineral may develop at much lower temperatures than in the dry way used by Hautefeuille.

From the general association of these minerals then, it is argued that high pressures and relatively high temperatures obtained during chloritic action. The temperature was probably below 500° C., at which in the presence of liquid mineralizers, fusion of the granite might begin.[7] Disussion will be made below of the relative behavior of the chlorite and epidote with respect to the rutile and sericite during progressive sericitization.

Sulphidation of the femic minerals, and probably also of the magnetite, was observed ordinarily to have occurred in the Butte granite without necessary movement of the iron from these min-

[1] Leith, Bull. U. S. Geol. Surv. 239, 1905, p. 118. Also Adams, F. D., forthcoming Carnegie Pub., "On Results of Experiments on the Behavior of Rocks under Pressure." Results given before New York Acad. Sci., Jan., 1911.

[2] Clarke, Bull. U. S. Geol. Surv. 330, 1908, p. 332.

[3] *Idem*, p. 340.

[4] Bourgeois, Encyc. Chim., t. II, Metalloids, 1er appendice, "Reprod. Artif. Min.," Paris, 1884, p. 90.

[5] P. Hautefeuille, *Ann. chim. phys.*, 4th Ser., 1865, Vol. 4, p. 129.

[6] *Min. pet. Mitth.*, Vol. 11, 1890, p. 325.

[7] Harker, "Nat. Hist. of Ign. Rocks," McMillan, 1909, p. 186; Lehmann, "Alltkryst. Schiefergest.," 1884, pp. 54, 55.

erals, and such action is proved possible experimentally. To affect this naturally there must have been introduction of sulphur in some form in excess of that required to satisfy available iron in any incoming minerals. The experimental work just referred to shows that this sulphur could have been introduced as hydrogen sulphide, elemental sulphur, or potassium sulphide. The process may mean also deoxidation of iron and development of sulphur dioxide, as discussed in connection with chalcocitization. It seems unnecessary to suppose, however, that sulphur was the only reducing agent present, since carbon monoxide[1] may as reasonably be supposed. If carbonates were thus formed, they seem to have been decomposed by subsequent action of sulphuric acid except in tight veins and country rocks where some rhodochrosite and microscopic traces of other carbonates are still found.

The net result of the chloritic action is an alteration phase in which the maximum weight of chlorite for this granite, some 5 per cent., is developed. Pyrite is always present and may equal the chlorite in mass, but is replaced more or less by chalcocite in the shattered and porous localities. Epidote and rutile combined may approximate 1 per cent. by weight. One or 2 per cent. of secondary silica usually appears, and minute traces of carbonates have been detected in sections selected clearly away from veins. Sericite may or may not exceed chlorite in abundance, but is always evident. The sum of all the alteration products is usually under 20 per cent. of the volume, leaving more than 80 per cent. of the original components unattacked. This majority of primary constituents gives the rock the coarse granular texture of the fresh Butte granite, yet the darkening of the feldspars and quartz—possibly due to free sulphur—is a strong peculiarity of the chloritic phase. Mead's researches show that during the action pore space may double, amounting in highly chloritized samples to above 2 per cent., though their average porosity is below that figure. Density is therefore increased, in some instances as much as 5 per cent., as would be expected from such mineral transformations accompanied by only appreciable increase in porosity.

[1] Lincoln, ECON. GEOL., II., 1907, 262, 269.

As already pointed out the chemical migrations up to this point are by no means as large as physical observations would indicate.

Sericitic Phase; Physical Features.—While the slight sericitized chloritic phase passes gradually into the fresh granite on the one hand, it grades into a more highly sericitized rock on the other. The sericitic phase lies next to the veins and is commonly most intense where these are highly pyritized. None of the sericite is observed to have a characteristic silky luster, nor to show the micaceous cleavage ordinarily seen in sericitic schists. The dull luster of the sericite is discovered to be due to a slight kaolinization, as shown below. Indeed this kaolinitic action is scarcely absent from any specimen, whether apparently fresh, chloritized, or sericitized, and is especially likely to occur in shattered rocks in all areas of secondary sulphide enrichment. Possibly the absence of the schistose structure, as well as its unctious feeling when wet, and its whitish color, have frequently caused the mineral to be confused with talc, especially when occurring as vein gouge. Many occurrences exhibit silica distributed in granules, thus resembling a fine-grained quartz porphyry.

The highly sericitized phase is of extremely fine, dense texture. Its porosity, like that of the fresh and chloritic facies, is approximately 1 per cent. Here again, therefore, as pointed out in the discussion of the chloritizing action, volume seems to have remained constant in the body of the rock. *This feature of constant volume common to the chlorite and sericitic facies, which merge into each other geographically, presents additional evidence of their close relationship and common cause, and stands in striking contrast with loss of rock volume, or gain in pore space, during present-day leaching of fresh chloritic, and sericitic phases by cold meteoric waters.*

Even under extreme magnification the sericitic rock is a felt-like complex difficult to analyze. Ninety-five per cent. of it consists of three main components—quartz and secondary silica, sericite, and pyrite. Besides these it contains some kaolin, perhaps 1 per cent. of chlorite, and a few other minor components.

When orthoclase is invaded the sericite is observed to form first along fractures, cleavage planes, or other obvious channels. Fig. 9 illustrates this typical congestion along the cleavage planes of orthoclase, and the presumably later, scaly formation occupying the interior of the orthoclase crystal. When all other non-metallic minerals are well nigh replaced by sericite, fibers of this mineral are observed to intrude themselves along fractures and into cavities of the quartz. No cases of entire replacement of all primary quartz were noticed; in general perhaps one third of the obviously primary quartz is unattacked. The secondary silica is detected as minute fillings in decomposed silicates. On account of this peculiarity and its occasional radial structure and absence of bubbles and apatite inclusions, it is usually rather easily distinguished from the primary quartz. As discussed beyond, the silica carried downward by later circulations or diffusions has been deposited chiefly in crystalline masses in veins and veinlets; it is therefore not often confusable with that more locally freed and deposited during sericitization. The small occurrences of chlorite in the sericitic rock are not confusable with the radiate silica, since they retain their greenish hues by natural transmitted light.

It is difficult to find an occurrence of the typical sericitic phase that is not impregnated with pyrite. Some of this pyrite bears no necessary close relation to even the smallest veinlets; moreover, even in the extreme cases of sericitization there may be seen occasional relations of pyrite to fibrous traces of former ferromagnesian minerals entirely isolated from any channels of circulation. The sulphide here occurs associated with rutile and other characteristic decomposition products of the femic minerals, is sometimes surrounded by films of secondary silica, and occasionally shows crystal faces. Such relations, all of which were observed in the chloritic facies, are again suggestive of pyritization of femic minerals by addition of sulphur to the iron contained therein.

Since these associations, and the steady increase in pyrite as well as sericite, may be traced from the earliest chloritic phase to

the most highly sericitic, they furnish evidences that the sericitic phase represents merely a general continuity of the action forming the chloritic. The facts brought out later, relating to probable changes in pressure and temperature during chloritization and sericitization are not in conflict with evidences that the two phases are the result of one continuous process.

It remains to be added that in the sericitic phase pyrite occurs not only in the fibrous portions where it still presents crystal forms, but is very generally disseminated elsewhere throughout the rock, almost invariably in granular, anhedral particles, thus differing again from the characteristic crystal forms that are the rule in the veinlets and veins in the sericitic rock. These distinctions are intended to show that the pyritization in the later stage was very probably accomplished differently from that in the earlier. Presumably that in the later stage was affected through introduction of both iron and sulphur, which replaced minerals indiscriminately and gave tight fillings in veins and veinlets.

The pyrite of the sericitic phase is rarely replaced by chalcocite, such replacement being observed only in shattered areas showing also considerable kaolin. The closest studies of polished faces and thin sections of rocks of the fresh, chloritized and sericitized phases have failed to reveal other copper minerals than this chalcocite within the country rock. Since the investigations by Simpson[1] indicate absence of copper from the lean pyrite in which no copper minerals can be detected microscopically, it seems highly probable that no other copper mineral than chalcocite exists at present within the unoxidized wall rocks.

The minor components mentioned above are apparently submicroscopic problems. The probabilities of traces of such secondary minerals as paragonite, zeolites, and carbonates have been mentioned. A minute crystal was determined with little doubt as zoisite; kaolin was found microscopically in almost every section examined. The proportions of these minerals excepting kaolin are indeterminate even by chemical computations; kaolin may be so determined approximately. The fact that the presence

[1] Econ. Geol., III., 1908, p. 635.

of kaolin may be detected microscopically and established chemically in an extremely sericitized phase is of much significance and receives further attention below.

Occurrence and Significance of Sericite.—The invariable association of sericite with the copper-bearing veins at Butte, and its occurrence with ore deposits elsewhere, have caused the writer to review the studies of this mineral from the time of its first distinction to the present. Its distinction, occurrence, origin, and significance are of especial importance in the study of metasomatic action.

It is reasonably certain that a large amount of the vein gouge of deep mines, and most of the micaceous materials of schists and slates—the so-called talc, soapstone,[1] kaolin, clay, etc.—is nothing other than sericite.[2] The abundance of the mineral and its common occurrence in metalliferous veins are causing more and more inquiry into its significance.

Sericite is a potassium-bearing[3] mica of the same composition[4] as muscovite.[5] It occurs characteristically in fine scales and fibers, often more or less compactly arranged in orientations similar to that of the mineral they replace, and having a silky luster when pure. These microscopic scales occasionally grow into larger flakes, yet the locus of deposition seems more or less discontinuous, resulting in the development of the disconnected scales. It is never found in unaltered primary igneous rocks, and while therefore believed to be secondary, is not found in rocks subjected only to the processes of weathering. Moreover, it is not produced by laboratory experiments under conditions anal-

[1] Eaton, Amos, "Index to Geol. of Northern States," pp. 147, 174, 286.

[2] Called "sericite" on account of its silky luster, by its first discoverer. See List, *Jahrb. d. Veriens. f. Nartukunde in Herzogth., Nassau*, VI., 1850, p. 126; VII., 1851, p. 66; VIII., 1852, p. 128. *Ann. Chem. u. Pharm.*, 81, 1852, pp. 181, 257.

[3] Laspeyres, H., *Groth's Zeitsch. Kryst.*, IV., 1880, p. 244.

[4] Dana, "Man. Min. and Petrog.," 4th ed., New York, 1887, p. 355. Of the many synonyms mentioned by Dana, only damourite is now much used, possibly because it designates what is usually considered an alteration product of muscovite. The others listed are commonly not distinguished from sericite in the sense of secondary muscovite.

[5] Dewey, Chester, Prof., *Am. Jour. Sci.*, 1st ser., I., 1819, p. 340.

ogous to those of weathering.[1] Indeed evidences show that the mineral actually breaks down in the belt of weathering. Probably Zirkel's statement[2] that sericite appears of characteristic freshness even in extremely decomposed rocks, is based on observations made on schists composed almost exclusively of sericite, thus having few drastic reagents such as oxidizing sulphides, to promote decomposition. The statement certainly does not accord with the more recently published researches of wider range, as summarized by Van Hise:[3] "The above alterations of muscovite all occur in the zone of katamorphism, and especially in the belt of weathering."

Since sericite is observed to be always of secondary origin, though not to form under conditions of weathering, its generation probably occurs under conditions of high pressure,[4] though its presence seems not always[5] to be an index of such conditions.

It seems probable from petrographic and chemical identities its presence seems not always[5] to be an index of such conditions. of temperature and pressure as muscovite, which to judge from its occurrence in pegmatites and other rocks crystallizing in connection with important amounts of mineralizers which escape under low pressure, is one of the low temperature[6] minerals of igneous rocks crystallizing under high pressure. To judge, however, from the evidences of sericitization found by Weed[7] in the

[1] Dittrich, M., *Z. f. anorg. Chem.*, 47, 1895, p. 151, finds that while potassium is absorbed from an $N/10$ solution of KCl by pulverized granite(?), presumably under atmospheric conditions, he was unable to detect sericite in the sample so treated.

[2] *Lehrb. d. Petrog.*, 2d Aufl., Leipzig, 1893, I., p. 340.

[3] Mon. U. S. Geol. Surv., 47, 1904, p. 338.

[4] Williams, G. H., Bull. U. S. Geol. Surv., 62, p. 62; Lehmann, J., "Untersuch. u. d. Entsteh. d. altkryst. Schiefergest.," Bonn, 1884, p. 136 et seq.; Benedicks, Carl, *Bull. Univ. Upsala*, VII., 1904–5, p. 281; Van Hise, *loc. cit.*, p. 338; Zirkle, *loc. cit.*, p. 341; Clarke, F. W., Bull. U. S. Geol. Surv., 330, p. 551.

[5] Weed, 21st Ann. Rep., U. S. Geol. Surv., 1900, II., p. 246. This reference does not specifically indicate high pressures; but see discussion, pp. — and —.

[6] Wright, F. E., *Am. J. Sci.*, 4th ser., Vol. 27, 1909, p. 421; Harker, A., "A Nat. Hist. of Igneous Rocks," New York, 1909, p. 186. Harker here cites also the somewhat doubtful determinations of Sorby, *Q. J. G. S.*, Vol. 19, 1858, pp. 453–500, showing by estimations from liquid inclusions that the Cornish granites solidified probably between 200° and 350° C.

[7] *Loc. cit.*, pp. 237 and 246.

Boulder hot springs, sericite may deposit from waters under very low pressure and at a temperature not above 164° F., (73° C.). The statement cited, namely, "metasomatic replacement is actively going on," probably means that the progressive action formerly affected is now to be observed in a series of thin sections properly selected to show the gradation. At all events it may be ventured that these unoxidized waters are only preserving from present-day weathering what remains of sericite developed under conditions of temperature and pressure quite higher than those exposed at the present state of erosion at Boulder, or even encountered in the shallow tunnel examined.

While usually developed under such exclusive conditions, sericite is further observed to have certain peculiar mineralogical affinities. Even in an admixture of plagioclase and orthoclase it forms first in the areas of plagioclase, although it doubtless obtains some of its alumina and a large amount of its potassa from the adjacent orthoclase.

Whatever the submicroscopic details of the process, which are discussed at some length by de Lapparent,[1] it may be observed that during sericitization there is a regional as well as a local notable migration of materials, and that water must ordinarily be added to the composition of the rock for the formation of sericite. Additional water would seem especially essential when as in some occurrences, such anhydrous minerals as topaz, andalusite, garnet, quartz, and the like, are replaced by sericite.[2]

All the above references indicate that where sericite can be certainly identified it becomes a useful corroborative criterion in the interpretation of previous hydrothermal, high-pressure conditions. It has been observed to be always a secondary mineral not adjusted to the belt of weathering. The mineral develops typically by hot spring action, presumably under relatively high pressure, though probably not above critical conditions for water.

[1] de Lapparent, J., *Bul. Soc. fr. de Min.*, To. 32, 1909, p. 232 et seq. de Lapparent here points out that additional alumina as well as potassa is required for the formation of sericite from the albite molecule, and refers to water as the active agent of transportation. Cf. also Williams, Lehmann, and Benedicks, *loc. cit.*

[2] Schmidt, C., *Neues Jahrb. f. Min.*, Beil. Bb., 4, 1886, p. 428.

According to de Lapparent its formation implies local and regional migration of materials, water being present from the beginning. Evidently all magmatic and siliceous metasomatic minerals, hydrous and anhydrous, excepting possibly primary muscovite, give place under such action to sericite. This seems due to the position of potassium in the electro-chemical series, which "gives, with some exceptions, the order in which they (the metals) replace one another from solutions of their salts."[1]

The presence of sericite in the ore deposits at Butte may therefore be taken as evidence of secondary mineralization by local and regional migration of materials in unoxidized, thermal waters, the latter not necessarily in a gaseous condition, though at pressures markedly higher than that of the atmosphere.

Relations of Non-metallic, High-temperature Minerals.—Besides its value as a geologic thermometer and barometer sericite bears certain interesting mutual relations during these alterations to the minerals chlorite, epidote, and rutile, here named in the general order in which they reach maximum importance during hydrothermal alteration of the Butte granite, sericite finally dominating all.

These minerals are discussed above as representative of moderately high temperatures and pressures during their formation; their relative behaviors during chloritization and sericitization at Butte indicate that conditions there may have slightly varied in a regular manner during the processes. In the well-defined chloritic phase there are present chlorite and sericite in perhaps equal amounts—about 5 per cent. each—and smaller occurrences of epidote and rutile—about 0.5 per cent. each. In the ultimate sericitic product there is abundant sericite, rutile has decreased but little, chlorite is much depleted, while epidote seems to have disappeared. These contrasting associations admit of at least two possible explanations. (1) The chlorite and epidote may have found place to form and exist at first because materials for the formation of sericite were for the time being unavailable. When these constituents were supplied, water being increased and

[1] James Walker, "Physical Chemistry," 4th ed., London, 1907, pp. 347 and 349.

potassa derived from orthoclase by intense action later, at which time the solutions would become alkaline, sericite supplanted both chlorite and epidote, and ultimately much of the quartz. (2) The earlier solutions may have acted at higher temperatures and pressures, conditions suitable for the development of chlorite and epidote, and of sericite and rutile as well. The later solutions, however, were presumably cooler and under lower pressure, thus giving conditions of unstability for the former named pair, while the latter pair, being of the more persistent[1] type, still remained, if they did not develop.

The second theory is in close agreement with the observed varying conditions of temperature and pressure under which sericite and rutile may form, as already discussed (page 58). The greater abundance of sericite in the highly altered phase next to the veins is probably dependent also on the time factor, the mineralizers having acted longer through the immediate vein walls. On the whole however, the formation of these two particular sets of minerals would seem to indicate mineralization of the granite by hot spring action decreasing in intensity toward the cool, inactive conditions of present time.

Sericitic Phase; Chemical Features.—Since the chloritic phase so grades from the fresh granite into the sericitic phase as to represent only a less complete stage of alteration than that in the sericitic, the chemical conditions of sericitization have necessarily received treatment in part in connection with those of chloritization. Further qualitative explanation seems necessary, however, for certain transformations observed in the ultimate product.

Previous to the sericitic replacement of the quartz much of the primary silica appears to have been transported locally, though probably not eliminated from the rock. Such local migration seems highly probable in the presence of the lyes arising from the decomposition of the alkaline silicates. The fact that no secondary sodium minerals were identified, especially when taken in connection with the fact that Mead's collection of com-

[1] U. Grubemann, "Die krist. Schiefer," Berlin, 1904, p. 55; W. Lindgren, ECON. GEOL., II., 1907, p. 122.

plete analyses of the sericitic rocks shows soda as the oxide least in amount, indicates that this constituent is clearly lost. Thus while conditions favored formation of sericite, they did not promote growth of paragonite, nor other soda-bearing persistent mineral; the potassium combined as a silicate, the sodium probably as a soluble carbonate or even as the more soluble hydroxide. Of interest also is the occurrence of epidote in the earlier chloritic phase, with zoisite apparently absent, while in the more exclusively sericitic phase the reverse is the case, zoisite appearing in minute traces. This observation would indicate reduction of iron by incoming sulphur, sulphides, or possibly carbon monoxide, and either its conversion into pyrite or its improbable loss from the rock. The pyrite present here in excess of that warranted by the original iron content of the granite may have been deposited by action of hydrogen sulphide, sulphur, or potassium sulphide on iron introduced in solution, perhaps as bicarbonate.

Summary of Chloritic and Sericitic Phases of Alteration.— The complete alteration of the essential constituents of the original granite may be traced briefly as follows. The femic minerals and magnetite are ordinarily attacked first, passing through the preliminary chloritic-epidotic, slightly pyritic condition to the final sericitic-pyritic, slightly chloritic state. When this transformation is well begun, plagioclase begins to pass over into sericite and secondary silica, and the commencement of this alteration is followed by the more direct passage of orthoclase into the same two minerals. At this stage zoisite is detected, while epidote has well nigh disappeared. Possibly paragonite occurs in traces, but it was not certainly identified; soda indeed seems not to have been needed by minerals developing under the existing conditions, and was therefore eliminated from the rock. Primary quartz gives place in a large degree to the invasions of sericite. But for its small amount and questionably accurate determination by any quantitative method, the persistent one fourth per cent. volume of titanic acid, existing finally as rutile, might well be used as a criterion of constancy of other minerals during these alterations.

Thus the two stages of hydrothermal alteration are seen to pass into each other very gradually, and while certain index minerals give evidence of differences in intensity of alteration at different times, the general nature of the activities has been much the same throughout. *The terms chloritic and sericitic become therefore phasal distinctions, referring rather to resulting products than to material change in processes.*

Vogt has discussed[1] such action, pointing out its chloritic and sericitic relationships, and calls it propylitization, essentially in agreement with Rosenbusch. Vogt defines the term thus: "Propylitization is a solfataric and thermal alteration affected by attack of hydrogen sulphide or alkaline sulphides, and often also of carbonic acid." Permanence of resulting carbonates seems well nigh impossible in association with the present sulphuric solutions, yet rhodochrosite is found in the tight veins, and there are microscopic traces of carbonates within the country rock. Presence of fluorite indicates an accompaniment not mentioned by Vogt in this connection. He states that propylitic action is confined to the later veins, for the reason that the "old veins" were formed at greater depths, hence at higher pressures whereby escape of solutions (and especially of dissolved gases, hydrogen sulphide, etc.) into the country rock was hindered. The writer is in accord with this statement in his conclusion above that the intensity of the hot spring action has decreased toward the inactivity of the present time.

From the facts that Vogt expresses surprise at the small chemical differences between the original and altered rocks as shown by analyses collected by Lindgren, and that the writer is unable to find later comment on the question, he infers that the propylitic action is traceable at Butte to an extent not hitherto discussed. The great difference in physical appearance after only scarcely noticeable chemical migrations has already received notice.

The ultimate result of the propylitic action on this rock is a whitish, dense-textured, siliceous, sericitic, pyritic complex, more

[1] "Gen. Ore Dep.," trans., 1901, pp. 660 et seq.

similar to greywacke than to the original Butte granite. While it shows less than 10 per cent. of primary quartz, its volume of free silica amounts to above 50 per cent. Some 40 per cent. of its volume is sericite, 5 per cent. pyrite, with perhaps 1 per cent. chlorite. Less than one fifth of 1 per cent. of copper minerals could be found outside the veins, and this in the form of chalcocite after pyrite in a sample from which kaolin had to be subtracted and the remaining chemical constituents recomputed to permit fair comparison of hydrothermal alteration phases. Mead's investigations show further that the average gravity of the sericitic samples has increased 4.6 per cent. over that of the propylitic phase, showing a total gain in gravity of 8.4 per cent. over that of the original granite sampled. Porosity remains approximately 1 per cent., or the same as that of the original unaltered granite, and the relatively unkaolinized chloritic phase. This condition is in strong contrast with the high porosity or low rock-volume of similar phases now being subjected to alteration by cold meteoric waters.

Definite conclusions from the above summary may be drawn more easily after a brief discussion of the activities of these meteoric waters.

Kaolinitic Phase; Alterations of Fresh, Chloritic, and Sericitic Phases of Granite near Surface.—Under surface conditions the plagioclase alters to kaolin and quartz perhaps even more readily than does orthoclase. Chlorite is not observed to form under conditions of exposure to weathering alone, yet limonite is abundant, and, doubtfully, some hematite in localities not exposed to sulphate waters. Almost all of the possibly abundant sericite seems to have broken down and disappeared.

Underground in the more porous areas of the sulphide zone chlorite and rutile are completely lost, while sericite succumbs more slowly, yielding a kaolinitic residue from which the secondary silica is largely abstracted. Limonite forms abundantly only in the open workings, where are deposited also in limited quantities sulphates of various bases in the rock, especially iron, magnesia, and lime, with occasionally those of copper and zinc, along with considerable quartz.

Kaolinitic Phase; Relations of Kaolin to Surface Conditions and to Porosity.—It has been pointed out that kaolin is found in all phases of alteration of the Butte granite, abundantly near the surface and to a limited extent in the most sericitic underground areas examined. The quantity is greater indeed in the sericitic phase than in the original granite occurring outside the district, perhaps because this sericite occurs ordinarily in areas of repeated faulting and is therefore usually so much shattered as to allow diffusion and percolation. It must be said moreover, that the freshest samples obtained from without the district are unduly kaolinitic because broken from the interior of ten-foot monoliths which stand out from the surface, and even though highly impervious, are perhaps more subject to weathering than if existing in the same locality a few hundred feet underground.

In the study of the underground areas of the copper district undergoing leaching at the present time it was observed everywhere that kaolin increases with porosity. The type specimen of the chloritic phase showed a porosity of 1.5 per cent., though in order to get what were thought to be average conditions, one sample testing 5 per cent. pore space had to be used. [In computing such a sample to minerals from Mead's analyses, it was necessary to give some 15 per cent. of volume to kaolin. The alumina and silica of this mineral were redistributed, as above indicated, so as to get a condition comparable to that of the type specimen, and the results found to agree closely with the minerals observed in thin sections of the firm-textured type rock of the chloritic phase.] For the study of the highly sericitized phase the set just mentioned contained analyses of firm samples of less than 1 per cent. porosity, none of which showed as much as 3 per cent. of kaolin. The increase in kaolin with increased opportunity for weathering is common to all localities in the Butte district. Lindgren[1] has indicated more specifically the formation of kaolin under oxidizing condtions, as follows:

> Kaolin has not been mentioned among the gangue minerals of any class of deposits except those formed or occurring under oxidizing influ-

[1] ECON. GEOL., II., 1907, p. 120.

ence, although the writer is well aware of the very general opinion to the contrary, and although in a paper on metasomatic processes referred to above he has himself formerly considered it as characteristic of certain classes of veins.

Kaolinitic Phase; Circulation and Interdiffusion of Bases during Sulphide Enrichment.—It may be objected that since kaolin is formed at all depths yet reached in the mines of Butte—some 2,000 feet below the present water level—the appeal to surface agencies is without force. The objections seem to find reply in the fact that topographic conditions were formerly probably much different from those now present, as already quoted from Emmons, and again from Weed on a following page. Yet while structural conditions seem to favor direct downward circulation to great depths at former times in this district, they can hardly be admitted as definitely proved. *Great oscillations of the water table appear less essential for the conditions observed however, if it be supposed that mere downward diffusion of oxidized and sulphatized solutions into the belt of saturation or cementation may account for much kaolinization and simultaneous enrichment in copper sulphide below the limits of circulation, as such, through interactions*[1] *between the silicates and the descending solutions.* Production of sulphides in the Butte deposits as contrasted with sulphates in Sullivan's empirical work, may be ascribed to mass action. *Vertical interdiffusion of the descending metallic solutes and the ascending non-metallic is obviously aided by their differential specific gravities.* On close examination many occurrences of kaolin formerly ascribed to hydrothermal action, because structural features seemed less propitious for other explanation than are apparent at Butte, may be more reasonably accounted for by this subtle interaction of minerals.

During transformation of the silicates quartz is relatively slowly lost both at the surface[2] and underground. The amount finally dissolved and carried out of the rock is evident from inspection of proportions of minerals computed from Mead's chem-

[1] Sullivan, U. S. Geol. Surv., Bull. 312, 1907, p. 64.
[2] Sales, *loc. cit.*, p. 16.

ical analyses, as well as from the relations of contents of mine waters to losses from granite during alteration. The movement of silica through excessive leaching of the sericitic phase of the wall rock is shown by the analyses just mentioned to be more than 15 per cent. of the entire rock, or above 20 per cent. of the siliceous content; yet since much of the quartz has evidently been deposited in the veins near at hand, the loss from the region is seen to be little and by slow stages. The writer has seen on the 1200-foot level of the Pittsmont mine a three-inch vein showing half-inch bands of sooty and solid chalcocite near walls of kaolinized sericite, and two inches of quartz comb-structure at the middle. Thus the relation of kaolin to surface, and to porosity underground, are of much significance in connection with downward enrichment in copper. The comb-structure of the definite quartz vein just described is in striking contrast with the massive quartz intermingled with the enargite in the relatively unkaolinized localities.

In a forthcoming paper Mead will take up the relations existing in the mine waters. It seems well to state here, however, that silica is lost in much higher proportions from the sericitic rock than it is carried in the mine waters, the proportions of silica to bases in these solutions being exceptionally small. This condition is borne out by the observation that in the fissures and veins of the granite there are found crystals of quartz in abundance, as already mentioned, while sulphates of the bases, minerals such as melanterite, gypsum, epsomite, are found only on the walls of workings where evaporation is active, and sodium and potassium salts of the abundant sulphuric acid do not seem to be deposited.

Kaolinitic Phase; Results of Superposed Action of Cold Meteoric Solutions.—The ultimate result of the weathering of the Butte granite, whether fresh, chloritized, or sericitized, as seen in the first 100 to 500 feet next to the surface, is a porous residue of quartz and impure kaolin stained with the more or less hydrated oxides of iron and manganese. This statement obviously means losses in all bases, even the refractory iron and manganese being much depleted. Gold and silver are here concentrated, but copper

is present, either as metal or oxides only in the lowest selvage next to the sulphide zone.

Much less extreme actions evidently due to cold meteoric waters are observed in the sulphide zone, and here the intensity of the weathering quite naturally decreases as depth increases. The color of the rocks is whitish to greenish. In localities where activities of meteoric solutions are evident, the luster of the sericite is dimmed by the presence of kaolin, which forms also from any feldspar, femic minerals, or chlorite that happen to be present. Obviously chlorite is not developed in this environment. Chalcocite is replacing pyrite, though some of the pyrite is lost through formation of the soluble sulphate radical. Occasionally a capping of sphalerite occurs on the veins at the top of the sulphide zone.

It is well nigh impossible to obtain a thin section of these extremely decomposed phases of rock, yet the best estimates microscopically show quantities of the minerals approximately as computed from chemical analyses. When contrasted with an extremely sericitic phase, silica is seen to have diminished 10 points, or 20 per cent., in the sericitized-leached phase; pyrite is going out; chlorite has practically disappeared; rutile is diminished; sericite is nearly half gone. On the other hand, chalcocite is nearly doubled; kaolin, less than 3 per cent. in any typical sericitic sample, is here almost 30 per cent. Instead of the 1 per cent. pore space obtaining in the fresh granite and throughout the propylitic phases, Mead has discovered in the leached areas as high as 29 per cent. porosity, with an average of 22 per cent.

Contrasts between Sericitic and Kaolinitic Phase, and Conclusions Following.—Attention is here directed to only the more obvious contrasts between the ultimate sericitic phase subjected to little if any subsequent alteration and this sericitized-leached phase in the sulphide zone. The chief dissimilarities are: constant porosity and volume with preliminary development of chlorite and epidote, progressive increments of sericite, silica, pyrite, and specific gravity, and no introduction of copper minerals into the wall rocks observed during propylitic action, on the

one hand, as contrasted with development of pore space, kaolin, and chalcocite, with decrease of rock-volume, breaking down of primary silicates and sericite and chlorite, and losses in silica, pyrite, and specific gravity in the rocks weathered or leached by cold meteoric waters, on the other. These antitheses are more clearly brought out in the following tabulation.

ALTERATIONS OCCURRING DURING PROPYLITIZATION OF BUTTE GRANITE CONTRASTED WITH WORK OF COLD METEORIC WATERS ON SERICITIZED PRODUCT IN SULPHIDE ZONE AT PRESENT TIME.

Chemical Alterations.

Actions during Propylitization.	*Actions of Cold Meteoric Solutions at Present Time.*
Iron gained.	Iron lost.
Sulphur added for iron sulphide.	Ferric, calcium, magnesium, copper, and zinc sulphates formed.
Losses in lime, soda, and magnesia; transformation of iron oxides to sulphide; decrease in all bases except potassa.	Losses in all constituents except alumina, copper, and water.
Gains in iron sulphide, silica, water (at first, then slight loss), alumina, potassa, copper (sulphide?), titania.	Gains in water and copper.

Mineralogical Alterations.

Non-metallic.

Development of sericite, quartz, pyrite, chlorite, epidote, rutile, rhodochrosite, fluorite—the last two in veins only. Femic minerals alter first; feldspars more resistant.	Development of kaolin, quartz, limonite (open workings and surface), sulphates. Feldspars alter first; femic minerals last, with no chlorite.

Metallic.

Development of enargite, bornite (?), wurtzite(?); in veins only.	Development of chalcocite, sphalerite.

Physical Alterations.

Porosity more or less constant.	Porosity increased.
Density increased.	Density decreased.
Energy stored.	Energy expended.

The contrasts in the above columns are very marked and except for sake of completeness scarcely need further emphasis to show the distinctive character of the processes operative in the two cases. The material increases in quantity of iron and its sulphidized condition in the sericitic alteration as opposed to its decreased and sulphatized state in that of the cold water is of much significance. A maximum point of hydration on the one hand, and a constantly increasing hydration on the other are in keeping with the culmination and disappearance of chlorite in the one action and the constant increase of kaolin in the other. Here may be noted the striking accordance of these observations with those of Vogt for foreign localities:

> As in the ordinary alterations of mica-rock and topaz-greisen so likewise in propylitization with chloritization and sericitization, it is, as a rule, the iron-magnesium silicates (mica, augite, hornblende) which first (before the feldspars) suffer alteration—in other words, offer the smallest resistance to the attacking solutions. On the other hand, mica, augite and hornblende are more resistant than the feldspars to the alterations which form kaolin.

The constant hydration and kaolinization follow closely the development of chalcocite. Such minerals as sericite, chlorite, epidote, rutile, wurtzite, are not observed to form during cold-water action. The constant porosity and increase in density during propylitic action agree with the observed molecular replacement of a rock of medium density by large quantities of such minerals as sericite and pyrite. The increase in porosity and decrease in density during cold-water leaching correspond with the solution and transportation of heavy bases by the sulphate waters. The formation of sulphides and complex silicates during primary mineralization represents a storing of energy later expended during their transformation into sulphates, kaolin, etc.

Thus there are observed to be close agreement in chemical, mineralogical, and physical characteristics in each type of alteration of itself, but a marked contrast when these characteristics are compared, each with each in the two types. The fact that the

results affected by propylitic action are diametrically opposed to those now being accomplished by cold meteoric waters acting on fresh and previously altered rocks leads to the conclusion that the chloritic and sericitic phases were produced from the original granite by heated agents—most probably in solution. This conclusion corroborates those drawn above from the study of sericite, per se, and in association with chlorite, epidote, and rutile.

Evidences thus far adduced from the study of the chloritic and sericitic alterations on the one hand, and the kaolinitic on the other, lead to the general conclusions that since the solidification of the original granite it has been altered by two successive processes of directly opposite nature. (1) By hot gases, or thermal solutions, or both, carrying among other constituents sulphur, carbon dioxide, and probably fluorine, as well as iron and silica. From their siliceous content it may be inferred that the solutions were basic, and from the abundance of sericite formed during the alteration it appears that the chief base present might have been potassa. To this process is applied the term propylitization, essentially as defined by Vogt. (2) The products of the propylitic alteration, as well as much of the original rock have been decomposed later by oxidized, and especially by sulphatized solutions descending from the surface to depths below present mining operations—some 2,800 feet—far below the present water table, and probably well below any previous water table. To this process the term kaolinization is applied in the light of evidence that kaolin is the residual representative of oxidizing conditions. *When considered as the product of interdiffusions below the water table, the kaolinitic phase is seen to extend below the limit of Van Hise's belt of weathering.*[1] *These conditions would seem to call for a relimitation of that important belt.*

RELATIONS OF ORE BODIES AND WALL ROCKS.

Classification of Veins and their Relations to Wall Rocks.—From field observations in the copper district it is found convenient to divide the ore bodies into three groups in accordance

[1] Mon. U. S. Geol. Surv., XLVII., 1904, pp. 163 and 409.

with the character of ores now extracted. (1) The quartz-pyrite-enargite-(bornite) veins. These are more closely associated with the sericitized country and more characteristic of the lower levels. The writer's observations for this paper do not include the heavy bornite veins of the western copper area of the district, yet he is led to believe they may be classed as indicated. (2) The quartz-pyrite-chalcocite veins. These are more closely associated with the kaolinitic phases and are more common to the higher levels. (3) A combination of (1) and (2)—indeed neither (1) nor (2) is believed to exist independently of the other to any appreciable extent. Besides the copper-bearing quartz-pyrite veins, there are numerous quartz-pyrite veins barren of copper.

Irregular indefinite vein walls below the oxidized zone are the rule in these deposits. Cases either of comb-structure or of vein-matter frozen to the walls are of rare occurrence in the sulphide zone. Where a vein is bounded by a relatively firm phase of country rock of essentially different mineralogical composition from its gangue, a few inches of gouge usually separates the ore body from that side, and of itself furnishes evidence that movement has taken place since the ore body was produced. In general where evidence of movement is lacking the high probability of origin of gangue from immediate wall rock may easily be traced both mineralogically and chemically. The gangue is thus seen to be composed of country rock altered in situ, the metasomatic replacement having been extreme in the veins probably only because they have been greatly crushed by repeated slight readjustments. The gouge just mentioned is normally the result of fine comminution of whatever materials border the planes of weakness. It is therefore ordinarily a siliceous, highly sericitic mass, darkened to some extent by fragments of femic minerals, but mainly by finely divided sulphides. It is seldom kaolinitic; indeed on account of its impervious texture, it is generally less kaolinitic than the more coarsely crushed gangue.

In the study of the vein minerals in the country rock well below the oxidized zone, and therefore little subjected to leach-

ing by surface waters, it is discovered that the essential depositions are of quartz, pyrite (chalcopyrite),[1] enargite-and-bornite,[2] chalcocite—originating evidently in the order named and intermingled with much sericite and but little kaolin.

A minor metallic vein mineral of importance in the present study is wurtzite, the rhombohedral sulphide of zinc, first certainly identified at Butte by Pearce,[3] "after some years of careful searching" for crystals, though he suspects this form of zinc in massive state. Although this discovery in the upper levels of the Gagnon mine was not in direct association with copper minerals, it is of significance in corroborating (see page 819) comparatively high-temperature conditions among the metallic minerals.[4] The writer has heard oral description of massive brown sulphide, such as that mentioned by Pearce, in association with enargite on the lower levels of the Gagnon mine, but has been unable to secure such a specimen from there or elsewhere in the district.

As already indicated, in the oxidized zone the veins are masses of silica carrying some clay, and are stained with iron oxides; they are not without pyrite, though devoid of more than traces of copper. The passage from the oxide to the sulphide zone is abrupt, and is marked occasionally by more or less extensive sheets of disseminated native copper. In one observed case the native copper was closely intermingled with chalcocite, and even with pyrite, but without enargite. The reaction in such a case may have been a very simple oxidation process, such as:

$$Cu_2S + 2O = 2Cu + SO_2.$$

Although cuprite and occasionally covellite are reported from similar occurrences at Butte, neither was discovered in this association. Quantitative chemical analyses of the pure sulphide revealed only chalcocite.

[1] Chalcopyrite is rarely present except in the northwestern portions of the district.

[2] This order for bornite is taken from Simpson's determinations referred to above.

[3] Trans. XVI., 1888, p. 63.

[4] P. Hautefeuille, *Compt. Rend.*, 52, 1861, p. 920. Hautefeuille here recounts the inversion of sphalerite into wurtzite on heating to redness.

As just indicated, chalcocite is present at the oxide-sulphide transition; it continues into depths below present mine development—2,800 feet. Sooty disseminated occurrences appear at all levels, and are not confined to the veins. Indeed a highly pyritized granite, where much shattered and therefore open to replacement, has been hoisted as ore, not uncommonly assaying above 2 per cent. copper.

It has been remarked that the enargite veins are more commonly associated with that glance appearing in the veins in depth. Although the enargite is present also in the higher workings, it has there typically[1] a capping of chalcocite, and occasionally of sphalerite, or a mixture of both. The chalcocite capping may appear as sooty particles, well-defined crystals, or massive coatings, and has been observed to form on pyrite at the expense of the enargite.

Primary and Secondary Concentration of Enargite and Chalcocite.—The observations that enargite is decomposed in areas of katamorphism with deposition of chalcocite, that its formation everywhere precedes that of chalcocite, that it is closely associated with sericite practically free from kaolin lead to the conclusions that the enargite not only did not deposit from cold meteoric waters, but that it came in with the hydrothermal mineralization at an earlier period. The reported occurrence of wurtzite[2] in veins showing enargite in depth would indicate still more certainly the higher temperatures of formation of enargite.

Notwithstanding the many investigations into its manner of origin, the generation of the chalcocite is of more doubtful determination. The possibility of the downward enrichment of copper deposits by deposition of chalcocite on pyrite and other sulphides of lower stability in the Schurmann series is well known from the discussions of S. F. Emmons, Lindgren, Weed, and others, and has been specifically demonstrated for these deposits by H.

[1] Sales mentions an exceptional case, ECON. GEOL., *loc. cit.*

[2] It will be noted that the four hydrothermal minerals employed thus far, namely, chlorite, epidote, rutile, and sericite, are all non-metallic, and that of these only sericite is commonly closely associated with enargite.

V. Winchell.[1] By means of sulphides of arsenic, lead, copper, iron, zinc, and with pyrite Winchell obtained precipitates of Cu_2S from a solution of $CuSO_4$ in the presence of SO_2—conditions typical of the sulphide zone at Butte.

The common association of solid copper glance with enargite and the general increase of the solid glance with depth, as contrasted with the occurrences of sooty, disseminated chalcocite free from enargite and more often encountered near surface—and now quite easily explained as replacement deposits after pyrite—have led to the inference by casual observers that there are two generations of chalcocite, primary and secondary, according as it occurs in solid or in sooty form. The writer has observed repeatedly under lens and microscope evidences of deposition of solid chalcocite about a nucleus of pyrite and may therefore say that the inference is not well founded. He is not prepared to state from those observations, however, that primary chalcocite does not exist in these veins. As shown by Bischof,[2] the hydrogen sulphide frequently detected in mineralizing solutions, and this is present in hot spring waters in the Boulder batholith, may deposit lustrous, crystalline precipitates of the metals when the solutions are dilute. Again, the possible reduction and conversion into pyrite of the original iron oxides of the granites during progressive propylitization would make probable the presence of SO_2, a condition which Winchell proves experimentally essential for chalcocitization.

The finely divided glance is of much wider occurrence than the solid type, and the dominance of the sooty variety seems reasonable from the facts that: (1) the pyrite commonly occurs in isolated grains or in shattered masses and therefore yields an incoherent replacement product; and (2) in most cases, especially in the upper portion of the sulphide zone, solution of pyrite is more rapid than importation of glance-forming constituents, so that the result is a porous replacement by chalcocite. If on the other hand deposition of glance kept pace with solution of pyrite, it

[1] *Bull. G. S. A.*, XIV., 1903, pp. 269–276.

[2] "Lehrb. d. chem. u. phys. Geol.," 2d ed., Bonn, 1866, III., p. 721.

appears reasonable that solid chalcocite would result, and such action may have deposited the solid bodies of glance in depth, or in any localities where the solutions carry less acid and oxygen. Thus it seems unnecessary to suppose the primary genesis of the solid bodies of chalcocite.

It may be added that when chalcocite has begun to deposit, presence of pyrite is no longer necessary to further the action, since copper sulphide may act as a precipitant of its own kind.[1] Thus either by balance of solution of pyrite and deposition of chalcocite, or by the attraction of kind for kind there would result the deposition of a non-porous, secondary body of chalcocite by downward enrichment through cold meteoric waters perhaps equally as well as through upward-moving, heated solutions.

The fact above noted, namely, that associated with these depositions of chalcocite are the more kaolinitic facies is of additional significance, indicating the possibility of enrichment from above. Mineral analyses computed from the complete chemical analyses which Mead has had prepared of typical run-of-mine, Butte sulphide ores indicate the usual contrasting conditions of kaolin and enargite.. They show also that kaolin is by no means as important as sericite in the veins, and that low sericite usually means high quartz in the gangue. In metallic content they emphasize the obvious fact that in these ore bodies the proportions of chalcocite depend more or less upon those of pyrite.

Besides what has already been said of the accessibility of these deepseated occurrences of kaolin and chalcocite to oxidizing solutions, Weed's conclusions may be added:[2]

> At Butte, Montana, the region has passed through several very prominent changes in level since Tertiary time. . . . These changes all caused a migration of the water level facilitating the process of weathering and enrichment, and the great bodies of copper ores of the region are believed to be in part due to this cause.

Certain considerations of interdiffusion and interaction, as discussed above, would seem to require less emphasis to be put

[1] Winchell, *loc. cit.*, p. 273.
[2] Trans. 30, 1901, p. 448.

upon these oscillations, the precise location and immensity of which it seems difficult to prove. Whether or not structural conditions alone, those of interdiffusion alone, or both combined are adequate to explain the present state of affairs, *it appears from the association of the chalcocite with high porosity, kaolinization, and other evidences of action of direct meteoric waters—notwithstanding the fact that it occurs also associated with enargite in depth—that there is no sufficient reason for regarding any of the chalcocite at Butte as primary in the sense that the enargite, pyrite, and, possibly the bornite appear to be.*

Researches into the probable primary conditions of deposition of chalcocite are being made in other districts, notably by Laney[1] in the Virgilina district of Virginia and North Carolina. Photographs of these ores show what is apparently a eutectic of chalcocite and bornite, but since the primary origin of the bornite is not established, proof is lacking that the interesting discovery means primary chalcocite.

In a recent article Ransome reviews in a general way the question of the origin of chalcocite, with the following excellent summary:[2]

> So far as our present knowledge of its occurrence goes, I believe we are justified in regarding chalcocite as a mineral rarely if ever formed except under the conditions of downward sulphide enrichment or by vadose sulphate solutions. Of course any such generalization is liable to be overturned by new evidence, but the burden of proof appears to rest at present upon those who support the view that chalcocite can be deposited simultaneously with quartz and pyrite or other sulphides characteristic of unmodified or primary veins.

SUMMARY OF OBSERVED CONDITIONS AFFECTING MINERALIZATION.

It appears that any well-justified conclusions as to the origin of the Butte copper ores and associates must take account of various

[1] Geol. Soc. Wash., meeting March 9, 1910. Discussed by Ransome, ECON. GEOL., V., 1910, p. 210. Photographs and private communication through Professor Leith.

[2] *Loc. cit.*, p. 211.

conditions more or less closely related to that mineralization the chief of which are here briefly summarized.

The Butte district occupies a middle area in the Boulder batholith, which is a relatively impervious mass of basic granite, probably of Tertiary age. It is related in chemical and mineralogical nature, therefore, as well as in time of formation, with other igneous rock closely associated with copper deposits in the Rocky mountains. Copper tests and traces of copper minerals have been reported from portions of the batholith not directly connected with this or any other mining district.

Significant igneous and structural features have formed since the granite began to solidify. Dikes and flows of differentiated materials have accompanied or immediately followed the solidification, one of which series, the Modoc porphyry, is closely related geographically with the copper veins, and is the last igneous feature preceding the faulting. The type of faults is exclusively normal, and it is well known that tensional rather than compressional faulting accompanies the cooling of magmas. These faults are mineralized in direct proportion to their ages, the oldest of the three sets being the heaviest copper producers. This faulting evidently continued until a much later time than the mineralization of the veins, and the consequent movement seems to have been highly effective in crushing both the fresh and previously altered granite adjoining and within the veins, thus greatly facilitating their further alteration and replacement. One of the latest faults is thought to have produced important migrations of the water table, a condition formerly considered necessary for downward sulphide enrichment. Evidences of vertical interdiffusion of metallic and non-metallic bases in solution seem to render less necessary the supposed conditions for the immense actual circulation downward.

What may roughly be called vertical zones of primary alteration exist below the limits of oxidation and grade from that of great intensity within the veins and in the immediate wall rocks to a relatively fresh granite some distance away. These vertical zones of alteration range roughly parallel to their obviously

related normal faults, or veins, and are therefore at right angles to the horizontally disposed oxide and sulphide zones. The alterations are similar in character to those accompanied by hot springs still existing in the batholith, notably at Boulder, Montana. The formation and disappearance, during progressive propylitization, of chlorite and epidote, minerals formed characteristically at high temperatures and pressures, as contrasted with the formation and persistence of rutile and sericite, minerals observed to form under a wider range of conditions, are too conspicuous to remain unnoticed. Close inspection and petrographical and chemical examination have revealed strong contrasts between the composition of the fresh and any phase of the propylitized granite, in some cases as much as 90 per cent. of the original constituents having been replaced. In the main the replacement products are sericite, silica, and pyrite. Certain constituents for the formation of these minerals were added to the rock, displacing materials essential to the original granite.

From what is known of the inversion temperature of sphalerite into wurtzite, and through more recent researches into the iron sulphide series—marcasite, pyrite, and pyrrhotite—the temperature of this propylitization may be estimated to lie between 575° and 400° C. Considering the probable refusion of the granite in the presence of such mineralizers, the higher temperature is probably too great.

A comparison of these results with observations on the work of cold solutions on the fresh and sericitized rock at present shows that sericite, silica, and pyrite are not only not being added, but are being actually decomposed and the constituents necessary for their development removed from the rock; in other words the effects of weathering are being superposed upon a generation of minerals themselves introduced subsequent to solidification of the Butte granite.

The first phase of the alteration is peculiarly pyritized in close association with crystals of femic minerals, and this in a rock of extremely little pore space. It is perhaps superfluous to mention that no traces of the organic precipitants of sulphides

and their allies are found in this rock. No marcasite nor pyrrhotite is reported from the district, to the writer's knowledge.

The first introduction of the silica and the constituents of the pyrite and sericite has apparently preceded the deposition of the copper minerals, though quartz and pyrite came in also later with the enargite.

There is a close relationship of the enargite to the highly sericitic areas, and this relation is more obvious in depth. While the enargite is evidently best adjusted to the sericitic areas, it is everywhere limited by the vein walls, none of it being discovered in the wall rocks in disseminated or other forms. The zinc sulphide, wurtzite, the relatively high-temperature enantiomorph of sphalerite, is found in the veins, and is considered an associate of enargite. Along the deeper levels, that is, well below the oxidized zone, are found not uncommonly rhodochrosite and occasionally fluorite, minerals containing respectively the carbon dioxide and fluorine repeatedly observed in magmatic emanations.

In contrast with the occurrence of the enargite with sericite and fresh pyrite there is a close association of the chalcocite with kaolinite and altered pyrite. The latter relation is more obvious near the top of the sulphide zone, where the chalcocite occasionally grades into native copper.

ORIGIN OF THE ORES.

The fact that the ore deposits at Butte exist in veins and are accompanied by abundant evidence of secondary mineralization by hydrothermal action throws out of court the question of their concentration in their present position by direct magmatic segregation. In seeking an origin elsewhere it may be supposed that, since copper is easily carried in cold solutions the ores were brought downward from formerly existing segregations, disseminations, or upward continuations of veins. It is generally observed, however, that pyrite, the common gangue of the apparently primary ores, is decomposed rather than precipitated by directly descending meteoric waters, especially in the absence of

organic materials, limestone, and the like. It is certainly true that both pyrite and enargite are being thus decomposed at present in these deposits. It has been shown, moreover, that minerals indicative of high temperatures and pressures were formed during the alteration of the country rock and associated with the ores, which would seem to shut out the possibility that the cold waters were operative during the first concentration. It follows that the primary mineralizers very probably did not descend from above.

It has been considered that the solutions, juvenile or deoxidized meteoric, could have proceeded more or less horizontally through the granite, picking up their load there and redepositing it in the veins. This process seems improbable, however, in view of the facts that the original granite is of extremely low porosity and carries only minute quantities of pyrite with questionable traces of copper. Moreover the comparison of representative analyses reveals no migration of constituents in any direction until considerable additions of pyrite have become evident. Sources of heat for the formation, and especially for the peculiar distribution of such minerals as the chlorite, epidote, rutile, sericite, pyrite, and wurtzite are but vaguely conceivable under this theory. These facts seem to render untenable the conception that lateral secretion could have abstracted the vein minerals from the rock mass and transported them to their present position, or even have accomplished the accompanying wall rock alterations. If, again, the mineralizing solutions be thought to have proceeded laterally into the district along the first faults, and thence outward into the country rock, it would appear that when these channels were offset by later faulting, mineralization at the intersection would have been greatly modified if not altogether discontinued; yet evidences of such retardation are not observed.

Thus it appears that either descending or lateral importation, by meteoric waters or otherwise, are improbable agents in the first concentration. The remaining possible means lies in solutions ascending along the veins. An appeal to this medium gives also:

1. A more conceivable source for the heat and pressure conditions as indicated by the thermometric and barometric minerals present, conditions having analogues in the present hot springs in the batholith.

2. An adequate source for the materials added, especially the sulphur, copper, arsenic, excess iron, and other elements found in the original granite only in quantities not amenable to concentration.

3. An obvious means of explaining the zones of hydrothermal alteration ranging parallel to the veins.

The two ultimate sources possible for these ascending waters are, (1) meteoric, and (2) magmatic.

1. The location of these deposits many miles within a comparatively impervious batholith renders difficult the conception that meteoric waters could have gained access to a point where their ascent finally became possible. The fact that they must have acquired heat for the depositions observed and that therefore they proceeded thence against the laws of heat circulation appears even more improbable. Granting, however, that these improbabilities might be explained away, an adequate source for the metals would remain only vaguely indicated by any theory employing heated meteoric waters as their carrier.

2. A supposition that appears to conform well with all existing conditions is that the origin of both waters and ores was in a cooling magma comparatively near the present surface— a state of affairs which might well exist locally within a large batholith. The Boulder batholith has crystallized from a relatively basic magma, and for such an association the metallic sulphides, arsenides, and the like have strong affinities. Since, however, the solution of such compounds in any silicate magma is a direct function of the temperature, and since they are of much higher gravity than the associated silicates, they would segregate downward as the magma cooled above. Into the interior of the magma would segregate also the water, hydrofluoric acid, carbonic acid, silica, and other residues from the crystallizing silicates, either retarded from escape by solidification above or more miscible in the lower environment.

At a relatively early period in the differentiation, cooling stresses probably caused openings in the crystallizing granite which were immediately filled by the acid intrusions of aplite and quartz-porphyry. The heated condition of the granite at this time is especially well indicated by the gradational character of its contacts with the dikes, these contacts usually grading over an inch or more (page 43, fig. 440). While the Modoc porphyry is next preceding the veins in time of origin, the fact that it is everywhere associated with later mineralization renders it impossible to discern whether or not the porphyry brought up with it appreciable quantities of copper.

After further differentiation and cooling the periods of definite faulting set in, and through these openings evidently there emanated the gaseous and liquid mineralizers bringing up the constituents shown to be added to the country rock, as well as the metallic constituents of the veins. A change toward less intense conditions of temperature and perhaps of pressure, is indicated by the early formation of certain minerals which do not appear in the ultimate alteration phase, this being made up of very persistent varieties.

Apparently no genetic connection exists between the rhyolite and the copper mineralization. In the vicinity of the School of Mines a lean copper vein is covered by some 20 feet of rhyolite, clearly later than the vein and non-cupriferous.

From the fact that no presumably primary copper minerals are found beyond the veins, one of the following inferences may be drawn. (*a*) Such minerals were deposited there and subsequently leached out. (*b*) The earliest mineralizers were rich in silica and the components of sericite and pyrite and so filled the rocks with these as to exclude the copper deposition coming later on. (*c*) The vein walls have acted as a filter, permitting the ready passage of the gases and certain active ions in solutions, offering much resistance to the sericitic materials and colloidal silica, and excluding the copper minerals altogether. (*d*) Some combination of the three processes mentioned. From his observations thus

far the writer is inclined to favor some form of hypothesis (*c*), which is well substantiated by experimental proof.[1]

It appears highly probable that the enargite, and perhaps also the bornite, may have been deposited by these ascending heated solutions, but such origin for the chalcocite is not well indicated by its occurrence. It may be shown theoretically, moreover, that the structural molecules of enargite, bornite, and tetrahedrite contain a molecule of cuprous sulphide. If therefore sufficient arsenic, iron, and antimony sulphides were confined with the cuprous sulphide to form the double salts mentioned, they would probably crystallize since, being more complex compounds, they could do so at a lower temperature.

The absence of positive evidences for the primary origin of the abundant copper glance in these deposits, however, is a very minor matter. The downward enrichment of pyritic copper deposits by decomposition of such minerals as enargite, bornite, and even chalcocite, by sulphate waters, and the reprecipitation of the copper in the form of chalcocite on pyrite and other sulphides below is of common occurrence in this and other districts. The association of kaolin in direct proportions with the chalcocite and decomposing pyrite and in inverse proportions with the enargite and sericite, together with the evidences of both the probable migration of the water table and the vertical interdiffusion of solutes all go to show that the depth of downward enrichment need not be supposed to depend upon the present position of the ground water level. At all events it is certain that the limit of this secondary concentration of chalcocite has not yet been reached, at a depth of nearly 3,000 feet.

Since the conditions of alteration both by hydrothermal solutions and by the probable interactions due to meteoric agencies are extremely irregular below the oxidized zone in this district, and changes of level of the region are likewise indeterminate, it does not seem possible at present to predict the depth of downward concentration. It is obviously more nearly impossible to foretell the downward continuation of the primary deposits.

[1] Sullivan, E. C., Bull. U. S. Geol. Surv. 312. Interactions between minerals and water solutions.

EDITORIAL[1]

GEOLOGICAL DIAGNOSIS.

The beginning of the New Year finds many of the technical journals interrupting the regular order of their published papers to introduce summaries of the progress of geological science during the past year. Imperfect as such summaries must necessarily be, they serve a useful purpose, for they bring clearly before us the most important advances of the year by laying emphasis on the significant writings and so disclosing the trend of geologic thought during the twelvemonth. Also, by the silent condemnation of intentional omission they clear away a portion of the fast-growing accumulation of ineffective and unnecessary papers with which the science is burdened, and help to hurry them on to their eventual journey to the waste basket.

To endeavor to establish any general criteria by which contributions to science might be judged serviceable or dismissed without comment as unworthy of mention, would be ambitious if it were not also presumptuous and unwise. The purposes which scientific writings may serve are too numerous and too varied to permit of their being subjected to any single method of analysis and the needs of the readers for whom they are designed are so different that a paper which may be of no value to one may be of great value to another.

A careful analysis, however, of the work which has been done in economic geology during the past fifteen or twenty years carries with it more than the emphasis of the lines along which progress has been made and the trend which geologic

[1] The signed editorials which it is designed to publish from time to time in these columns are expressions of individual views and do not represent the consensus of opinion of the editorial board.

thought is taking; it suggests a close connection between the value of any general paper and the ease with which the facts which are presented may be practically applied. The truth of this suggestion would appear more clearly if a complete survey of past contributions were possible, but a few of the many valuable papers which have appeared in this time will serve to show how dominant this connection has been, although often unconsciously, in the author's work. Vogt[1] in his description of the Norwegian nickel ores shows the steps by which he determined that the ores were igneous and leaves the reader in possession of a valuable set of criteria by means of which the same determination can be made on other ores in other places. Lindgren[2] in a paper on the genesis of contact metamorphic deposits outlines the characteristics of the deposits in such a way that they can be used in the recognition of similar deposits elsewhere. W. H. Emmons[3] in a paper on manganese in its connection with surface enrichment and placers puts his readers in possession of facts which may be used in the search for placers in the neighborhood of veins and in the estimation of the probable enrichment which is likely to have taken place on an undeveloped ore body. Many others might be mentioned in the same way. In nearly all of the papers which have proved to be of permanent value this class of facts is dominant although frequently unconsciously so.

If then the origin of an ore-deposit be of as great importance as it is believed to be, the value of a discussion may be measured by the facility with which the evidence of its origin may be applied to other instances of the same kind. If it be important to know whether an interbedded layer of iron ore is a sediment, older than the overlying and younger than the underlying bed, or is a replaced layer of limestone which has nothing to do with the sedi-

[1] J. H. L. Vogt, "Bildung von Erzlagerstätten durch Differentiationsprocesse in basisischen Eruptivmagmata," *Zeitschrift für praktische Geologie*, Vol. I., pp. 4–11, 125–143, 257–284, 1893.

[2] Lindgren, "The Character and Genesis of Certain Contact Deposits," *Trans. Am. Inst. Min. Engs.*, Vol. XXXI., pp. 226–244, 1901.

[3] W. H. Emmons, "The Agency of Manganese in the Superficial Alteration of Ore Deposits," *Bull. A. I. M. E.*, 1910, pp. 768–837.

mentation but has been formed long afterward, the evidence by which this may be proved will be of local and transient interest if it applies only to the single occurrence described, but will be of far reaching importance if it can be applied by any of the readers to any other occurrence of similar nature which they may themselves encounter. If it be important to determine whether a mica-schist were originally a shale or an intrusive igneous rock, the criteria for determination will be valuable if they are of general application—of little value if they are of individual application only.

In other words, the utility of the work which an author presents is dependent in no small degree upon (1) the determinative nature of his facts, and (2) the presentation of these facts in such a way that they may be readily grasped and applied by readers. It is not enough that his thought should be accurate and clear, that he should explain what, for instance, secondary enrichment is and how it is brought about. He should also show *how it may be recognized when seen.*

It seems somewhat singular that in a science which has so many practical applications as economic geology there has been so little conscious effort to assemble data into compendia whose main purpose is determinative. Medical science is much more clearly classified. It not only recognizes that group of facts which deals with the nature, causes and effects of disease, but elevates into a separate subject the symptoms by means of which the disease may be recognized and gives to this group of facts the title of Diagnosis.

Mineralogists, too, are not satisfied with the descriptions of species but have written much on the manner in which the minerals may be determined. Determinative tables are a *sine qua non* to successful mineralogical education. They constitute what might be called mineralogical Diagnosis.

These thoughts can not fail to suggest that much might be added to the usefulness of many geologic papers if the authors would collect together into a summary their determinative criteria in such a way that they could be most easily used by others.

Compendia of this kind could be compiled without serious labor and added to a paper, whatever may have been the author's object in writing it. However superfluous they might seem to one who is thŏroughly familiar with a subject they would be of great service to readers and it is believed would do much to assist in the collection of that body of knowledge which may be most readily defined as Geological Diagnosis.

J. D. IRVING.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

Sir: Mr. J. B. Tyrrell has opened the discussion of my paper on "Certain Natural Associations of Gold" with an interesting article in the last issue of your magazine. I venture to express a hope that others will participate in the discussion as its continuance would seem likely to prove profitable.

The $285,000,000 which I employed for the sum of the past and the estimated future productions of the Klondike was not my own figure, as Mr. Tyrrell infers, but was taken from a publication of the Canadian Geological Survey.[1] Revising Mr. Tyrrell's original estimate to conform with this figure (not by way of criticism, but to bring it more nearly up to date), I obtained 0.019 cent saved in the Klondike placers from each ton of original rock. This result is cited on page 273 of my paper, but the citation unfortunately reads "about 2 cents" instead of "about 0.02 cent" as it should. In this connection, it is amusing to note that a misplaced decimal point has crept into Mr. Tyrrell's own article, causing him to misquote my "0.019 c." as "0.19 c."

Turning to the broader aspect of the discussion, I cannot agree with Mr. Tyrrell that the fiftieth of a cent obtained in this manner can be legitimately used as the basis of even a rough approximation of the original gold content of the Klondike schists. This figure does not even represent the total gold in the Klondike gravels, but only that which has been, and probably will be, extracted. It should be corrected for alluvial gold lost in

[1] G. A. Young, Geological Survey of Canada, Report 1085 (1909), p. 129.

working placers, for alluvial gold in placers too low grade to work and for non-alluvial gold in the placers. But when suitable corrections have been made, one is little, if any, better off, as far as the present computation is concerned, since no reliable data are available for calculating the loss of gold during erosion. Mr. Tyrrell assumes that 66⅔ per cent. would be a high loss, but I can see no reason why it may not have been very much greater.

Since the chemical effects of weathering are slight in the Klondike, it would seem that only an inappreciable amount of the fine gold which probably made up by far the greater part of the original gold content of the Klondike schists can have found its way into the placers. If this is the case, the above computation, corrected for lost and unworked placer gold, might very properly be used as the basis for a rough approximation of the amount of coarse gold in the original rock, but of the total quantity of gold originally in the rock one could only say with safety that it must have been greatly in excess of this amount.

FRANCIS CHURCH LINCOLN.

REVIEWS

The Formation of Coal Beds. By J. J. STEVENSON. Proceedings of the American Philosophical Society, volume 50, 1911, pp. 1–116.

Under the above title Professor Stevenson publishes the first or introductory part of a monograph. This part, which bears the subtitle "An Historical Summary of Opinion from 1700 to the Present Time," is concerned with the questions of the conditions and methods of accumulation of the organic debris from which coals have been formed. Some attention is paid to the kinds of ingredient plant material, a branch of the subject almost inseparably connected with the conditions of accumulation.

Though the present paper may not constitute an actual contribution to our knowledge of the formation of coal, it is certainly one of the most valuable and useful publications on the subject. With a comprehensive knowledge of coal and from a broadly experienced point of view Stevenson has, in clear and succinct terms, presented most carefully prepared synopses of all the original or important papers on the subject. How voluminous and widespread this literature is will be appreciated by the many who have attempted to compass it. At the same time his sympathetic conservation of each author's spirit robs the product of monotony and uniformity. His account is most readable and interesting, notwithstanding the necessary brevity of treatment.

In a recent notice of Arber's booklet on coal the reviewer stated that so many theories relating to the formation of coal have been promulgated that it is difficult for the present generation to find a new one or do more than make new applications and revisions of the old ideas. Stevenson remarks that "one discovers that his own period is not so far in advance of days gone by as he had supposed; that his contemporaries, with all their advantages, have done little more, in many instances, than to place newer and finer clothing on the generalizations of earlier students who had worked within narrower areas; . . . he has discovered not only that there is little new under the sun, but also that much, which is good and important, soon passes from men's minds." There are probably few students of coal who are aware that both the argument for the *in situ* origin and the doctrine of the development of bituminous coals from lignites, and lignites from peats, date back to von Beroldingen's discussions published in 1778.

Many have asked why, if the correct theories were long ago promulgated, is there still such controversy over even the main or fundamental propositions. The answer is first that not all coals (peats) were laid down under similar conditions or are composed of similar ingredient matter. This is now admitted by nearly all. But the second and more important reason is that the writers have lacked breadth of field observations and the study of coals of all kinds. Men who have happened exhaustively to examine one of the really very rare cases of transported organic matter (allochthonous deposits) have argued for transportation in most, if not all cases. Some who found great numbers of spores in a particular coal concluded that all coals must be largely composed of spores. Other authors, ignorant of the occurrence of bituminous coals and sub-bituminous coals or lignites in the same series and basin, formed from the same plants in a similar state of disorganization, have insisted that lignites never existed as peats and that higher grade coals were never lignites. Many articles are inspired by national prejudice or partisanship. Too much of the literature is based on narrow or very insufficient observation and is largely academic or theoretical. In fact, many of the papers are contributed by chemists, who have had little or no knowledge of coals of different sorts as they exist in beds, basins, and formations of varying ages. Lack of adequate field knowledge and consequent citation of real broadly comprehensive as well as detailed evidence and illustration, explains why many of the primary questions regarding the formation of coals have remained so long mooted.

In view of Professor Stevenson's wide experience and field studies of coals in Europe, the Arctic, and in the various systems of this continent, we expect much in the way of new applications of old theories and final solutions of special problems.

DAVID WHITE.

Rock Minerals—Their Chemical and Physical Characters and Their Determination in Thin Sections. By JOSEPH P. IDDINGS. 2d Edition. Revised and Enlarged. N. Y. John Wiley & Sons, 1911. Pages 617. Illustrated by many figures and a colored plate. Price $5.00.

The second edition of this well-known treatise is larger by sixty-nine pages than the first edition, issued five years ago. The enlargement comprises additional descriptions of important minerals occurring in pegmatites and ore bodies, and a few others occurring in metamorphic and sedimentary rocks. By the insertion of these descriptions the author meets the criticism to which the earlier edition was subjected—that it did not deal with the minerals of most interest to engineers: *i. e.*, those of economic value. The number of new minerals described is about

eighty, but these include about fifteen opaque minerals, which are treated very briefly. It would have added greatly to the value of this portion of the book if the author had referred to the methods employed by students of metallography to distinguish between opaque crystalline substances, such as those described by Campbell & Knight,[1] which are those developed by Leo,[2] which are based on the tarnishes produced by the treatment of polished surfaces by various reagents.

Several errors that had crept into the earlier edition have been rectified in the present one and there has been added a paragraph on the character and cause of the halos sometimes observed around inclusions. The plan of the book and the order of arrangement of the minerals described in it remain unchanged.

W. S. Bayley.

The Sedimentary Deposition of Oil. By Murray Stuart, B.Sc., F.G.S., Assistant Superintendent, Geological Survey of India. Records Geological Survey of India, Vol. XL., pt. 4, 1910, pp. 320–333.

That the oil of the Burma field was, in some way, deposited in the sediments as oil, and not as undecomposed organic matter, either vegetal or animal, and that it was deposited in the sediments in practically its present state, is the chief conclusion presented by the author of this paper, which is of more than ordinary interest and value.

Accepting the organic origin of petroleum as "proven beyond doubt," and that in most beds other than limestone it is mainly of vegetable origin, Mr. Stuart conceives that the decomposition of the organic debris proceeded elsewhere than in the strata themselves, and yet in such places that the oil would be retained and collected until it was liberated upon the surface of streams or rivers which were depositing the sediments, the oil becoming enveloped in the latter. Accordingly he supposes the decomposition under bacterial action to have occurred in closed lagoons or swamps, so that the oils could rise to the surface and form a layer. Breaching of these lagoons would permit the outflow of the oil, commingled with the sands and muds of turbid river drainage, and the precipitation, so to speak, of the oil in the transported sediments. The manner of the deposition of the oil in the sediments is the most important point developed in this paper.

Observing the relatively rapid disappearance of the oil drainage from the ground about the wells into streams in the oil fields, and having in mind the supposed affinity of the oil for particles of clay, as proposed

[1] This journal, Vol. 1, No. 8, pp. 751–776, and Vol. 2, No. 4, pp. 350–366. based upon the differences in texture revealed by etched surfaces, and

[2] Max Leo, "Die Anlauffarben. Eine Neue Methode zur Untersuchung Opaker Erze und Erzgemenge." Dresden, Theo. Steinkopff, 1911.

by Boverton Redwood and M. J. Munn, the author proceeded to study the phenomenon of the disappearance of the oil in sediment-laden, turbulent water. The examination of the streams appeared to show that the oil was carried down in sediments deposited on the bottom or along the sides of the streams. To determine the cause of such deposition Stuart carried out several experiments, which may be described, largely in his own language, as follows:

Samples of clay from the Kama series, the same which contains oil in Burma, were finely pulverized in a mortar in order to reproduce as far as possible the sediment borne by the rivers in Kama time. Sixty-six grams of this finely powdered clay was then added to 350 c.c. of water which had been previously agitated with oil and left to stand for twenty-four hours in order to permit it to take into solution anything possible from the oil, the latter being the crude Yenangyaung petroleum. To the mud and water in the flask was then added .20 c.c. of oil and the mixture was shaken for thirty seconds. On allowing the sediments to settle the surface of the water became quite free from all trace of oil, which had been carried down to the bottom with the muddy sediments. Further additions of oil, each time followed by a brief shaking and settling, were repeated until a total of 14 c.c. of oil had been "completely carried down to the bottom by the sediment, leaving the surface of the water perfectly clear and free from oil; the sides of the flask were also perfectly free from oil." When still more oil was added a slight show remained on the surface of the water, whence the author concludes that 14 c.c. was all the oil that 66 grams of sediment could carry down. The addition of larger quantities of oil at a single time gave the same results, even when quantities as large as 5 c.c. were introduced at once. The experiments seemed to show that muddy sediment which when compressed or solidified into shale occupies about 23.5 c.c. (the specific gravity of shale being approximately 2.8) can carry down with it 14 c.c. of the native petroleum. In order to learn whether the character of the oil affected the result a second experiment was tried, in which 28 grams of powdered shale were employed, and refined American oil, which is much less viscous than the native petroleum, was introduced. "In this case this sediment carried down 10 c.c. of oil, which is to say that sediment, which when solidified occupies approximately 10 c.c., carries down 10 c.c. of the light American oil."

To ascertain how the oil was carried down by the shale particles examination of the sediments in the flask was made with a high-power microscope (¼-inch objective). This showed that the oil was merely mechanically mixed with the sediment, and that it was "the small size of the shale particles that made it impossible for the globules of oil to

escape between them and so reach the surface. There were no instances of globules of oil containing particles of shale." It appears, therefore, that the oil is first broken up into separate particles in the turbulent water, the muddy particles probably assisting in this work. Oil and water being non-miscible, the particles of oil immediately assume a spherical shape, due to surface tension. These globules of oil correspond to those existing in an emulsion of oil and water, except, however, that in the emulsion the globules can come in contact with one another and coalesce, forming finally two layers, one of oil and the other of water, whereas in the muddy solution the oil globules are held apart by the particles of mud, these mud particles being wet with water and therefore non-miscible with oil. On the other hand, the oil globules cannot come together, owing to the fine state of division in which the mud particles exist. They are therefore carried down, mechanically mixed with the mud particles. When the number of oil globules in the mixture is too great—that is, when too large a percentage of oil is added—some of the oil globules come into contact and coalesce into larger globules, which have sufficient buoyancy to make their way to the surface against the downward-falling mud particles, and the result is a slight cover of oil on the water, as noted above, when the added percentage of oil is excessive.

In the experiment in which refined American oil was used the volume of the oil particles held in sedimentation is approximately equal to the aggregate volume of the shale equivalent of the mud. The author regards it probable, however, that many of the oil globules in the precipitate are individually bigger than the individual shale particles. The larger percentage of the light American oil of low viscosity carried down by the sediment, as compared with the percentage of the more viscous oil, is explained by the greater ease with which the former breaks up into fine globules, the more viscous oil being more resistant. The oil-bearing sediment, therefore, consists of "minute mineral particles which are solid, impervious to water or oil, and, practically speaking, incompressible; scattered amongst these are the globules of oil which are too big to pass between the particles of mud; and around and between all is what may be described as a matrix of water. This sediment is, of course, porous to water, that is to say, water can pass through it until it settles or is compressed so compactly that the grains come into contact with one another, so closing the passages between the grains." A point emphasized is that "this sediment is impervious to oil. It is because it is impervious to oil that the oil globules are forcibly held and contained in it, the fineness of the mud particles and the fact that they are wet with water, and that the spaces between the particles are filled with water, making it impossible for the oil globules to pass through them."

Naturally a portion of the oil may be squeezed out of the muds by the spatula on the side of the flask or in a press.

Stuart concludes that the agitation of thirty seconds in the flask is perhaps relatively insignificant in comparison to the agitation which the same quantity of oil would undergo during an immensely longer period on the surface of a moderate-sized river, such as the Irrawaddy. The Kama clays are regarded as deposits of fine mud containing oil globules laid down in the normal course of events in salt water some distance out at sea. As with most deposits of land sediments, occasional sandstones are interbedded with the deposits of mud particles. Eventually the muds are compacted, partly owing to gravitation and partly to weight of superimposed strata, the water, squeezed from the lower beds, finding its way up through the overlying sediments. "A point will be reached in this way when the lowermost mud will be so compactly compressed that it contains little water, and the oil globules find it impossible to retain their spherical shape. When this point of compression is reached the oil globules will become pressed out of shape into the interstices of the mud, until each globule comes into contact with its immediate neighbors; they will then coalesce, and under the compression of the mud bed, caused by the weight of the superimposed strata, oil will be pressed out of the mud until a point is reached when the solid particles which composed the sediment are all in contact with one another. When this happens compression will, of course, necessarily cease in that particular bed. The oil which is pressed out of the mud will be forced into the overlying sand, which is, practically speaking, incompressible under the pressure at present being discussed, that is to say, that pressure of this order, which succeeds in pressing oil out of the oil-bearing mud, is incapable of causing any significant compression in the sand beds, the grains already being in contact with one another. . . . The oil which is pressed out of the mud into the overlying sand will replace some or all of the water which occupied these spaces between the sand grains. The water so replaced can still find its way through the overlying strata because they have not yet reached that state of compression which will affect the contained oil globules. The oil which has been pressed into the sand cannot percolate through the overlying mud, as I have already explained, and therefore it is confined with probably some salt water in the sand bed." The oil cannot go down because the compression is greater below, and because the compression of the mud will take place from the bottom upward.

The presence of salt water is to be expected under conditions described above "because the shales which have been pressed free of practically all their oil would still be somewhat oily and so particularly impervious to water. The original salt water which was included with the oil in

the sands would therefore be preserved in them until they become either exposed naturally or tapped by a well."

The oil-carrying sediment of the experiment, after settling, was freed from nearly all its included water by filtering over a vacuum filter, when it was found that water only had been extracted and that no oil came through the filter. In opposition to the assumption that the latter fact was due to the wetness of the filter paper stands the observation that there was no accumulation of oil at the bottom of the sediment, and that the topmost layers of the mud, after the extraction of nearly all the water, was apparently as strongly oil-bearing as the layers immediately above the filter paper. By squeezing the sediments it was, however, possible to expel a part of the oil.

The theory and experiments described above are regarded by the author as fully accounting for the origin, deposition, and occurrence of the oil in the Burmese field, and in fact, in all fields. There are many who will dissent from some of the propositions presented in this paper, but Mr. Stuart's observations of the capacity of muds to carry down oil, and particularly his demonstration of the state of the oil in the sediments, are not only interesting but illuminating. In the judgment of the reviewer, oils developed in the ordinary processes of decomposition of the organic matter in the deeply buried rocks would at the outset, and probably do, exist in extremely small globules in the midst of the fine sediments containing the organic matter; so that it may not be absolutely necessary to agree with the first proposition of the author that "The deposition of oil therefore is purely a matter of gravitation. The oil becomes mechanically mixed with the sediment, and the fineness of that sediment renders it impossible for the oil to separate itself; the mixture of sediment and oil, being still of higher specific gravity than water, falls to the bottom and is deposited as a sedimentary deposit."

DAVID WHITE.

RECENT LITERATURE ON ECONOMIC GEOLOGY.

COMPILED BY

G. F. LOUGHLIN and G. E. GOODSPEED, Jr.

METALLIFEROUS DEPOSITS.

COPPER.

Copper Deposits of the Appalachian States. By W. H. WEED. Bull. U. S. Geol. Survey, No. 455, 1911, 166 pp., 5 plates, and 32 text figures.

Recognizes several different types of deposits. Descriptions arranged according to states.

The Copper Handbook, Vol. X., 1910-1911. By H. J. STEVENS. Houghton, Michigan. 6 × 9, 1902 pp.

Gives notes on 8,130 mines and companies and 100 pages are devoted to the copper deposits of the world. There are also chapters on the history, metallurgy and uses of copper.

GOLD AND SILVER.

General Report on Tanami Goldfield and District. By L. C. E. GEE. R.E.E. Rogers, Adelaide, South Australia, 1911, 22 pp.

The Ore Deposits near Pinos Altos, New Mexico. By S. PAIGE. Bull. U. S. Geol. Survey, No. 470–B, pp. 101–117. 1911.

Describes geology and ore deposits (fissure veins and replacements).

Notes on the Economic Geology of the Ramsey, Talapoosa, and White Horse Mining Districts in Lyon and Washoe Counties, Nevada. By J. M. HILL. Bull. U. S. Geol. Survey, No. 470–B, 1911, pp. 91–100.

Describes areal and economic geology.

Geologic Relations of Ore Deposits in the Elkhorn Mountains, Montana. By R. W. STONE. Bull. U. S. Geol. Survey, No. 470–B, 1911, pp. 67–90.

Describes general geology and occurrence of the ores.

Gold-bearing Ground Moraine in Northwestern Montana. By F. C. SCHRADER. Bull. U. S. Geol. Survey, No. 470–B, 1911, pp. 54–66.

Describes geology and occurrence of the gold.

Geology and Mineralization of the Upper St. Joe River Basin, Idaho. By J. T. PARDEE. Bull. U. S. Geol. Survey, No. 470–B, 1911, pp. 31–53.

Briefly describes the areal and structural geology, the types of mineralization, and the mines and prospects. Indicates the more and less favorable areas for prospecting.

The Economic Geology of Carson Camp, Hinsdale County, Colorado. By E. S. LARSEN. Bull. U. S. Geol. Survey, No. 470–B, 1911, pp. 22–30.

Gives brief descriptions of the general geology and the ore deposits, descriptions of mines. The ore bodies are gash veins in silicified Tertiary volcanics, and consist of barite, enargite, galena, sphalerite, chalcopyrite, pyrite and marcasite. The production is expected to come from small rich shoots.

The Auriferous Gravels of the Trinity River Basin, California. By J. S. DILLER. Bull. U. S. Geol. Survey, No. 470–B, pp. 3–21.

Describes general and local conditions, and discusses the outlook for placer mining.

A Replacement of Rhyolite Porphyry by Stephanite and Chalcopyrite at Leadville. By C. N. FENNER. Sch. of Mines Quarterly, vol. XXXI., No. 3, 1910, pp. 235–240.

Gives microscopic descriptions, illustrated by 5 micro-drawings, Concludes that the porphyry was first partially replaced by chalcopyrite and later was further replaced by stephanite.

The Tertiary Gravels of the Sierra Nevada of California. By W. LINDGREN. Prof. Paper, U. .S Geol. Survey, No. 73, 1911. 226 pp., 28 plates, 16 text figures.

This report traces a part of the history of the Sierra Nevada, the great range which, for 300 miles, divides the central valleys of California from the deserts of the Great Basin. It presents an account of the Tertiary formations of the range and deals especially with the origin and distribution of the gold-bearing gravels. Contains detailed descriptions of the area by quadrangles. The illustrations include geologic maps and sections and halftone plates showing features of hydraulic mining.

Geology and Ore Deposits of the Breckenridge District, Colorado. By F. L. RANSOME. Prof. Paper, U. S. Geol. Survey, No. 75, 1911. 187 pp., 33 plates, 29 text figures.

This report gives the results of an investigation of one of the most important mining districts of Colorado, including descriptive and economic geology, topographic and geographic maps and numerous halftone plates and text figures showing geologic features. The minerals of the district are listed and their characteristics noted. The important mines are described in detail and general conclusions are drawn as to the economic future of the mining industry in this region.

The Mineral Region of Collakuasi (Chile). By M. C. GONZALES. Eng. and Min. Journal, Nov. 11, 1911, pp. 956–957.

A brief description of the mineralogy and occurrence of the ore (fissure veins in andesite) and of mining methods. The important minerals are basic sulphates and silicates of copper carrying gold and silver.

Gold Placers in Bolivia. By M. ARMAS. Eng. and Min. Journal, Oct. 28, 1911, pp. 855–858. Illus.

Gives description of the gold-bearing gravels and methods of working.

The Helester Mines of California. By W. H. STORMS. Eng. and Min. Journal, Oct. 28, 1911, p. 858.

Gives location, method of mining and a short account of the geology of the ore deposit.

Porcupine after the Fire. By H. E. WEST. Eng. and Min. Journal, Oct. 21, 1911, pp. 795–796.

A description of the various claims as they are at the present time with a few paragraphs devoted to the geology of the region.

Alluvial Gold Deposits in Quebec. By F. CIRKEL. Eng. and Min. Journal, Nov. 25, 1911, pp. 1035–1038.

Gives history of mining in Beauce county and a geological description of the region; also present methods of mining and testing the gravels.

IRON.

The Cheever Mines, Port Henry, N. Y. By G. C. STALTZ. Eng. and Min. Journal, Oct. 21, 1911, pp. 809–812.

Gives a short history of the mines and a description of mining and milling methods. About 1½ pages are devoted to the occurrence of the magnetite which may have been of sedimentary origin.

The Geology of the Lake Superior Region. By C. R. VAN HISE and C. K. LEITH. Monograph U. S. Geol. Survey, No. LII., 1911, 641 pp., 49 plates, 76 text figures.

An exhaustive treatise representing the first attempt to give a connected account of the geology of this region as a whole with special reference to the iron- and copper-bearing formations for which it is famous. Attention is directed primarily to general features of correlation of the formations, to the geologic history of the region, and to the origin of the iron and copper ores. The volume contains accurate maps of all the producing districts, a general geologic map of the region, diagrams and halftone reproductons of photographs of minerals.

IRON AND MANGANESE.

Iron Ores in the Montevallo-Columbiana Region, Alabama. By C. BUTTS. Bull. U. S. Geol. Survey, No. 470–F, 1911, pp. 3–18.

Describes the limonite deposits at Shelby, that west of Brierfield, and minor deposits of limonite and hematite.

Comparative Sketch of the Pre-Cambric Geology of Sweden and New York. By J. F. KEMP. N. Y. State Mus. Bull. 149, 7th Rep. of the Director, 1910, pp. 93–106. Albany, 1911.

A summarized description of the Swedish formations, noting similarities to, and differences from, those of the Adirondacks.

Notes on the Geology of the Swedish Magnetites. By D. H. NEWLAND. N. Y. State Mus. Bull. 149, pp. 107–119, 7th Rep. of Director, 1910. Albany, 1911.

A general review of the modes of occurrence and genesis of the ores, showing the complexity of geological and mineral features. As a whole the deposits are fairly distinct from those found in the Pre-Cambric of New York, though between individual mines of the two regions certain similarities may be apparent or genetic relationships indicated.

Der Erzberg bei Aufmetz. By WEHMANN, Bergbau, July 6 and 21, 1911, 2½ pp.

Zur Bildung der anhydrischen Eisenoxyderge. By H. WÖBLING. Glückhauf, Sept. 16, 1911, 2½ pp.

Das Eisenerzvorkommen und die mutmasslichen Eisenerzvorräte in der Gegend von Rudobanya im Borsoder Comitat. Oest. Zeit. f. B. u. H., June 24, 1911, 1¼ pp.

Ueber das geologische Alter und die wirtschaftliche Bedeutung der Eisenerzlagerstatte von Schandelah in Braunschweig. By HARBORT. Zeit. f. prakt. Geol., Sept., 1911, 4 pp.

Nipisiquit Iron Ore Deposit, Gloucester Co., New Brunswick, Canada.

Map 25*A*. Geological Survey, Canada, 1911. A geological and topographical map with contour intervals of 20 feet and on scale 400 feet to 1 inch.

LEAD AND ZINC.

Notes on Lead and Copper Deposits in the Bear River Range, Idaho and Utah. By R. W. RICHARDS. Bull. U. S. Geol. Survey, No. 470–D, 1910, pp. 3–13.

General geologic description and brief local descriptions.

Lead and Zinc in the Metalline Mining District, Northeastern Washington. By H. BANCROFT. Bull. U. S. Geol. Survey, No. 470–D, 1911, pp. 14–26.

Describes geology, the distribution, character and origin of the ores, and the different prospects.

Das Blei-und Zinkerzvorkommen von Altini bei Massa marittima in Toskana. By SCHNASS. Gluckauf, July 15, 1911, 2 pp.

RARE METALS.

The Arsenic Deposits at Brinton, Virginia. By F. L. HESS. Bull. U. S. Geol. Survey, No. 470–E, 1911, pp. 3–9.

Describes the geology (briefly), the deposits (impregnation veins of arsenopyrite, in quartz mica schists, adjacent to aplite or pegmatite intrusions), the character of the ore, and the metallurgy.

NON-METALLIC. DEPOSITS.

ASBESTOS.

The Types, Modes of Occurrence and Important Deposits of Asbestos in the United States. By J. S. DILLER. Bull. U. S. Geol. Survey, No. 470–K, 1911, pp. 3–22.

CLAY.

Preliminary Report on the Clays and Clay Industries of Oklahoma. By L. C. SNIDER. Bull. 7, Okla. Geol. Survey, Norman, pp. 270.

COAL.

Coals of the State of Washington. By E. E. SMITH. Bull. U. S. Geol. Survey, No. 474, 1911, 206 pages, 8 plates.

A discusson of the character and quality of the coals of the State, giving analyses, methods of sampling, and detailed descriptions, by counties, of the mines and coals. A map of a portion of western

Washington, showing the distribution of coal mines and prospects, and halftone plates illustrate the bulletin.

Contributions to Economic Geology, 1909.—Part II. Mineral Fuels. By M. R. CAMPBELL, geologist in charge. Bull. U. S. Geol. Survey, No. 431, 1911, 254 pp., 12 plates, 4 text figures.

Contents include:

The southern part of the Cahaba coal fields, Ala., by C. BUTTS.

The Powell Mt. coal field, Scot and Wise Co.'s, Va., by M. R. CAMPBELL and E. G. WOODRUFF.

The eastern part of the Bull Mt. coal field, Oregon, by J. S. DILLER and M. A. PISHEL.

The Black Mesa coal field, Ariz., by M. R. CAMPBELL and H. E. GREGORY.

Coal deposits near Pinedale, Navajo Co., Ariz., by A. C. VEATCH.

Coal in San Benito Co., Cal., by M. R. CAMPBELL.

Mount Mulligan Coalfield. By L. C. BALL. Queensland Govt. Mg. Journal, Aug. 15, 1911, 8¼ pp.

Die Ausbildung des Flözes Plasshofsbank in der Wittener und Bochumer Hauptmulde, Westphalia. By RATHE. Glückauf, Sept. 23, 1911, 10 pp.

Die diluvialen Kohlenlager Savoyens. By SCHEIBENER. Zeit. f. prakt. Geol., Sept., 1911, 3 pp.

Der Zusammenhang der westlichen mit der östlichen Flözgruppe des Ostrau-Karwiner Steinkohlenreviers und die Orlauer Störung im Lichte der neueren Aufschlüsse. By MLADEK. B. u. H. Rundschau. July 20 and Aug. 5, 1911. (16½ pp.)

Das Rossitz-Zbeschau-Oslawaner Steinkohlenrevier. By E. PANEK. Oest. Zeit. f. B. u. H., July 29, Aug. 5, 12, 19, and 26, 1911.

Die Kohlenführung und Grösse des staatlichen Saarbrücker Berechtigungsfelds. SCHLICKER. Preuss. Zeit. f. Berg.-Hult. u. Sal., Vol. 59, Part 3, 1911, 20½ pp.

Ueber die Genesis des Stockheimer Steinkohlenflözes. By P. KRUSCH. Glückauf, Oct. 14, 1911, 6½ pp.

Bighorn Coal Basin, Alberta. By G. S. MALLOCH. Memoir No. 9–E, Canada Dept. of Mines, Ottawa, pp. 74; illus.

The Edmonton Coal Field, Alberta, Canada. By D. B. DOWLING. Memoir No. 8. Geological Survey, Canada, 1911, p. 59.

Gives in detail the location and thickness of various coal seams in the vicinity of Edmonton. Numerous analyses are given of the coals

There is a topographic map and a map with isobathic lines showing the depth of the Clover Bar seam below the surface.

DIAMOND.

Speculations Regarding the Genesis of the Diamond. By O. A. DERBY. Jour. Geol., Vol. XIX., No. 7, 1911, pp. 627–631.

Suggests that, in view of the probable deep-seated origin of the serpentinization of the diamond matrix, the diamond itself may have resulted from as yet unknown reactions favoring its concentration from ascending solutions of carbon in gaseous forms.

FLUX.

Dolomite for Flux in the Vicinity of Montevallo, Shelby County, Alabama. By C. BUTTS. Bull. U. S. Geol. Survey, No. 470–K, 1911, pp. 23–25.

Fluorspar near Deming, New Mexico. By N. H. DARTON and E. F. BURCHARD. Bull. U. S. Geol. Survey, No. 470–K, 1911, pp. 31–43.

Describes general geology and the occurrence and character of the fluorspar deposits. Discusses economic conditions which, though not discouraging, are not very attractive.

Fluorspar Mining at Roseclare, Ill. By E. F. BURCHARD. Eng. and Min. Journal, Dec. 2, 1911, pp. 1088–1090.

Chiefly a description of working methods and production. Geologic occurrence briefly summarized (fissure veins carrying fluorspar, calcite, galena and blende).

GRAPHITE.

Graphite near Dillon, Mont. By A. N. WINCHELL. Bull. U. S. Geol. Survey, No. 470–K, 1911, pp. 26–30.

Discusses the occurrence and origin.

MEERSCHAUM.

Die Gewinnung des Meerschaums in den Gruben bei Eski-Schehir Fleck. Bergbau, Sept. 28, 1911, 1½ pp.

MINERAL PAINTS.

Paint Shales of Pennsylvania. By B. L. MILLER. Bull. U. S. Geol. Survey, No. 470–I, 1911, pp. 3–14.

Gives general and local descriptions of the occurrences and uses of black, yellow, and red shales.

OIL AND GAS.

The Largest Lamp Black Factory. By B. S. STUTLER. Oil and Gas Journal, July 13, 1911.

A brief description of the manufacture of lamp black from natural gas at Grantsville, W. Va. 9,143,560 cubic feet of gas are consumed daily.

Contributions to Economic Geology, 1909, Part II. Mineral Fuels. M. G. CAMPBELL, geologist in charge. Bull. U. S. Geol. Survey, No. 431, 1911, 254 pp., 12 plates, 4 text figures.

Contents include:

Natural gas in N. Dakota, by A. G. LEONARD.

The San Juan oil field, San Juan County, Utah, by H. E. GREGORY.

Gas and oil prospects near Vale Cr. and Payette, Idaho, by C. W. WASHBURNE.

Preliminary report on the geology and oil prospects of the Cantua-Panoche region, Cal., by R. ANDERSON.

Present Status of Natural Gas Development in Pennsylvania Oil Fields. By F. C. CLAPP. Oil and Gas Journal, Nov. 9, 1911, pp. 840.

The newer pools of oil and gas are being opened up by deeper drilling.

General Geology of the Oakland City, Ind., Area. By W. S. BLATCHLEY, Oil and Gas Journal, Oct. 19, 1911, p. 12.

Gives the stratigraphic geology of the region.

Distribution of Petroleum and Gas. By L. L. HUTCHINSON. Oil and Gas Journal, Nov. 2, 1911, pp. 4–8.

Gives the geographic and stratigraphic distribution throughout the world.

The San Juan Oilfield of Utah. By G. D. JAMES. Eng. and Min. Journal, Dec. 2, 1911, pp. 1082–1084.

Discusses the probable, local unfavorable conditions and the most promising areas for prospecting and the relation between oil and magnetic variation. Advises deep drilling.

PRECIOUS STONES.

A Mexican Opal Mine. By T. M. M. MACFARLANE. Informes y Memorias Instituto Mexicano de Minas y Metalurgia, Vol. II., No. 4, 5 pp.

A Mexican Opal Mine. By T. M. M. MACFARLANE. Eng. and Min. Journal, Oct. 28, 1911, p. 842.

A short description of the mines at Queretaro. The opals occur in a spherulitic rhyolite.

PHOSPHATES.

Preliminary Report on a Portion of the Idaho Phosphate Reserve. By R. W. RICHARDS and G. R. MANSFIELD. Bull. U. S. Geol. Survey, No. 470–H, 1911, pp. 3–71.

A detailed description of the geology accompanied by several maps. It is thought very possible that the region contains the most extensive phosphate fields of the world.

A Reconnaissance of the Phosphates in Western Wyoming. By E. BLACKWELDER. Bull. U. S. Geol. Survey, No. 470–H, 1911, pp. 84–113.

Describes general geology, with map and several structure sections showing the position and distribution of the phosphate series.

Rock Phosphate near Melrose, Montana. By H. S. GALE. Bull. U. S. Geol. Survey, No. 470–H, 1911, pp. 72–83.

Describes the location, structure, character and extent of hitherto unprospected deposits; discusses the use, price, market, and manufacturing possibilities.

SALINES.

Potash Salts. Advance chapter from Mineral Resources of the United States, Calendar year 1910. By W. C. PHALEN, 24 pages (tables of analyses).

First gives an outline of the use of potash salts in the United States, with tables showing amount used in the various industries. Then a brief description of the German deposits. The last third is devoted to the possible sources of potash in the United States.

Petrographisch-geologische Untersuchung des Salzgebirges an der oberen Aller im Vergleich mit dem Stassfurter und Hannoverschen Lagerstättentypus. By BECK. Zeit. f. prakt. Geol., Sept., 1911, 19½ pp.

STRUCTURAL MATERIALS.

Bull. U. S. Geol. Survey, No. 470-G. 1911, 134 pp., 4 plates, 9 figures.

Contents:

Variegated marble southeast of Colera, Shelby Co., Ala., by C. BUTTS. 3 pp.

Supplementary notes on the granites of Massachusetts, by T. N. DALE. 49 pp.

Clay near Calhan, El Paso Co., Colo., by G. B. RICHARDSON. 4 pp.

Clay resources of the Murphysboro quadrangle, Ill., by E. W. SHAW. 5 pp.

Notes on some clays from Texas, by A. DEUSSEN. 50 pp.

Gypsum deposits in Eagle Co., Colo., by E. F. BURCHARD. 120 pp.

Survey publications on stone, cement materials, clays, gypsum, lime, glass-sand, etc.

Limestones of Oklahoma. By L. C. SNIDER. Stone, Nov., 1911, 2½ pp.

SULPHUR.

Sulphur Deposits near Soda Springs, Idaho. By R. W. RICHARDS and J. H. BRIDGES. Bull. U. S. Geol. Survey, No. 470–J, pp. 3–7.

Gives geology, descriptions of the springs and the sulphur deposits. Suggests a volcanic origin of the sulphur. The deposits are of doubtful value.

WATER.

Ground Water in Juab, Millard, and Iron Counties, Utah. By O. E. MEINZER in coöperation with the State of Utah, C. TANNER, State Engineer. Water-Supply Paper, U. S. Geol. Survey, No. 277, 1911, 162 pp., with 5 plates and 13 text figures.

Summarizes physiography and geology, gives a general discussion of the occurrence, quality, and use of ground water, and gives detailed discussions for different areas.

Geology and Water Resources of Estancia Valley, New Mexico, with Notes on Ground-Water Conditions in Adjacent Parts of Central New Mexico. By O. E. MEINZER. Water-Supply Paper, U. S. Geol. Survey, No. 275, 1911, 89 pp., 14 plates, 7 text figures.

Describes the physiography, geology, soils and climate of this valley, which although for a long time sparsely settled, has only recently become accessible by railroads. Gives special attention to the water of the valley, discussing its source and disposal, head, recovery, and quality, and the proper mode of irrigation.

Surface Water-Supply of the United States, 1909. Prepared under the direction of M. O. LEIGHTON.

Part I. Water-Supply Paper 261. North Atlantic Coast, by H. K. BARROWS, C. C. COVERT, and R. H. BOLSTER.

Part VI. Water-Supply Paper 266. Missouri River Basin, by W. A. LAMB, W. B. FREEMAN, and F. F. HENSHAW.

Part IX. Water-Supply Paper 269. Colorado River Basin, by W. B. FREEMAN, and R. H. BOLSTER.

Geology and Underground Waters of Northeastern Texas. By C. H. GORDON. Water-Supply Paper, U. S. Geol. Survey, No. 276, 1911, 78 pp., 2 plates, and 6 text figures.

Describes general geology and underground water conditions. Gives review by counties.

Geology and Underground Waters of Southern Minnesota. By C. W. HALL, O. E. MEINZER, and M. L. FULLER. Water-Suply Paper, U. S. Geol. Survey, No. 256, 1911, 406 pp., 18 plates, and 9 text figures.

Describes physiography, geology, quality of water, problems relating to wells and public water supplies. Gives descriptions by counties.

The Geochemical Interpretation of Water Analyses. By C. PALMER. Bull. U. S. Geol. Survey, No. 479, 1911, 31 pp., 1 text figure.

Discusses chemical character of water, classification, and interpretation of analyses. Reaches the conclusion that natural water may be definitely characterized, if the salts dissolved in it are recognized not as a load but as a chemical system of balanced values.

Some Stream Waters of the Western United States, with chapters on Sediment carried by the Rio Grande and the Industrial Application of Water Analyses. By H. STABLER. Water-Supply Paper, U. S. Geol. Survey, No. 274, 1911, 188 pp.

Describes methods of taking and analyzing samples and gives results of sampling at different stations. The percentage by weight and volume of sediment in the Rio Grande is shown in a series of tables.

Quality of the Water Supplies of Kansas. By H. N. PARKER, with a **Preliminary Report on Stream Pollution, by Mine Waters in Southeastern Kansas,** by E. H. S. BAILEY. Water-Supply Paper, U. S. Geol. Survey, No. 273, 1911, 375 pp., 1 plate, 1 text figure.

Describes stratigraphic geology and artesian waters. Discusses quality of underground waters by counties, and of surface waters by drainage basins. The character of pollution is shown by analyses, and the effect of mine water pollution on fish and on metals is discussed.

REGIONAL REPORTS.

Mining in the Straits of Magellan. By H. W. EDWARDS. Eng. and Min. Journal, Dec. 2, 1911, pp. 1091–1093.

A brief account, chiefly historical.

Annual Administrative Report of the State Geologist for the year 1910. By H. B. KÜMMEL. Bull. N. J. Geol. Survey, No. 1, 1911, 43 pp.

The Mineral Industry of New Jersey for 1910. By H. B. KÜMMEL and S. P. JONES. Bull. N. J. Geol. Survey, No. 5, 1911, 24 pp.

Economic Geology of Richmond, Va., and Vicinity. By N. H. DARTON. Bull. U. S. Geol. Survey, No. 483, 1911, 47 pp.

Describes the rocks of Richmond and vicinity with special reference to the high grade granite and brick clays. Accompanied by a map showing the economic geology of the district and plates illustrating quarry methods.

The Mount McKinley Region, Alaska. By A. H. BROOKS, with **Descriptions of the Igneous Rocks and of the Bonnifield and Kantishna Districts,** by L. M. PRINDLE. Prof. Paper, U. S. Geol. Survey, No. 70, 1911, 234 pp., 18 plates, 30 text figures.

A detailed account of an exploratory journey from the Pacific seaboard through the Alaska Range along the northwest base of Mount McKinley to Panama and Yukon rivers with full descriptions of the stratigraphy, structure, and geologic history of the whole Mount McKinley province and a concise statement of the present knowledge of the mineral wealth of the region. Summarizes all available information concerning climate, vegetation, agricultural lands and game. Illustrated by topographic and geologic maps, geologic sections and halftone views.

Mineral Resources of Alaska. Report on Progress of Investigations in 1910. By A. H. BROOKS and others. Bull. U. S. Geol. Survey, No. 480, 333 pp., 13 plates, 19 text figures.

Contains general reports and special reports on the Eagle River region, the upper Susitna and Chistochina districts, the Matanuska coal fields, the Willow Creek gold region, the Yukon-Tanana, the Bonnifield, Innsko-Iditarod, and Skungnak regions, and the Squirrel River placers.

Geology and Mineral Resources of the St. Louis Quadrangle, Missouri-Illinois. By N. M. FENNEMAN. Bull. U. S. Geol. Survey, No. 438, 1911, 73 pp., 6 plates, 1 text figure.

Describes general and economic geology, including deposits of clay and shale, quarry rock, lime, cement materials, sand and gravel, oil and gas, coal and water resources.

Zur Systematik der Lagerstätte "Schneeberg" in Tirol. By LAZARCOIC. Zeit. f. prakt. Geol., Sept., 1911, 4¾ pp.

Die Erzlagerstätten zu Kamsdorf in Thüringen. By HEYER. Glückauf, July 8, 1911, 8¼ pp.

Twentieth Annual Report of the Bureau of Mines, 1911. Vol XX., Part I.

Contents:

Statistical review; mining accidents; mines of Ontario.

Silver in Thunder Bay district, by N. L. BOWEN.
The Sturgeon Lake Gold Field, by E. S. MOORE.
Gold Fields of Lake of the Woods, Manitou and Dryden, by A. L. PARSONS.
Vermilion Lake pyrite deposits, by E. S. MOORE.
Iron and lignite in the Mattagami Basin, by M. B. BAKER.
Notes on the salt industry of Ontario, by N. L. BOWEN.
A geological trip to Scotland, by W. G. MILLER.
The mining law of Ontario, by S. BRICE.
The Lauretian system, by W. G. MILLER and C. W. KNIGHT.

Mineral Resources of Wyoming and the Mining Laws of the State and the United States. Pp. 102, C. E. JAMISON, State Geologist, Cheyenne, Wyoming.

Report of the Colorado State Bureau of Mines for the years 1909 and 1910. By T. J. DALZELL, Commissioner of Mines, Denver, pp. 110.

ORE DEPOSITION.

The Genesis of Ore Deposits. By E. K. SOPER. Eng. and Min. Journal, Nov. 4, pp. 897–900; Nov. 11, pp. 947–949, 1911.

A general summary of existing ideas.

Sulphide Orebodies in Oxidized Zones. By C. R. KEYES. Eng. and Min. Journal, Oct. 21, 1911, pp. 793–794.

Sulphide ore may be contemporaneous with oxidized ore, especially where the zone of oxidation is large.

UNCLASSIFIED.

A Report on the Approximate Cost of a Canal between Bay Head and the Shrewsbury River (N. J.). By H. B. KUMMEL. Bull. N. J. Geol. Survey, No. 2, 1911, 20 pp.

The State Geological Surveys of the United States. Compiled under the direction of C. W. HAYES. Bull. U. S. Geol. Survey, No. 465, 1911, 177 pp.

Contains accounts of past and present surveys written by the state geologists.

Mineral Resources of the United States, Calendar Year 1910. Advance chapters as follows:

The cement industry in the United States in 1910, by E. F. BURCHARD, 1911, 71 pp., 1 plate, 2 text figures.

The gypsum industry in 1910, by E. F. BURCHARD, 1911, 19 pp., 1 plate.

The production of mineral paints in 1910, by E. F. BURCHARD, 1911, 23 pp.

The production of bauxite and aluminum in 1910, by W. C. PHALEN, 1911, 15 pp.

The production of manganese ore in 1910, by E. F. BURCHARD, 1911, 15 pp.

The production of anthracite coal in 1910, by E. W. PARKER, 1911, 13 pp.

The production of fluorspar and cryolite in 1910, by E. F. BURCHARD, 1911, 16 pp.

The production of abrasive materials in 1910, by W. C. PHALEN, 1911, 17 pp.

The production of quicksilver in 1910, by H. D. MCCASKEY, 1911, 20 pp.

The production of peat in 1910, by C. A. DAVIS, 1911, 12 pp.

The production of sulphur and pyrite in 1910, by W. C. PHALEN, 1911, 18 pp., 2 text figures.

The production of iron ore, pig iron, and steel in 1910, by E. F. BURCHARD, 1911, 36 pp., 2 text figures.

The production of gems and precious stones in 1910, by D. B. STERRETT, 1911, 58 pp.

The production of salt and bromine in 1910, by W. C. PHALEN, 1911, 19 pp., 1 plate.

Gold, silver, copper, lead, and zinc in the Eastern States in 1910 (mine production), by H. D. MCCASKEY, 1911, 19 pp.

The production of slate in 1910, by A. T. COONS, 1911, 17 pp.

Zinc and cadmium in 1910 (spelter production), by C. E. SIEBENTHAL, 1911, 51 pp., 3 text figures.

A Point of View on Ore Reserves. By B. B. LAWRENCE. Eng. and Min. Journal, Oct. 14, 1911, pp. 743.

The Mineral Industry, Its Statistics, Technology and Trade During 1910. Edited by A. H. FAY. McGraw-Hill Book Co., N. Y. Vol. XIX., 6 × 9, 904 pp., illus.

Scheme for Valuing Ore in Stopes. By L. FRASER. Eng. and Min. Journal, Oct. 21, 1911, pp. 802–803.

By plotting two new factors on a stage map, instead of the customary assay-width data, variations in values become more apparent and instructive.

SCIENTIFIC NOTES AND NEWS[1]

T. A. JAGGAR, JR., professor of geology at Massachusetts Institute of Technology, has been granted leave of absence for the remainder of the year in order that he may perfect plans for the volcanic laboratory at Halemaumau, in the Hawaiian Islands.

F. G. CLAPP, of Pittsburgh, was in the Gulf Coast oil fields of Louisiana and Texas early in February.

RALPH ARNOLD returned to Los Angeles, February 4, from a trip to Trinidad.

H. W. TURNER returned to San Francisco early in February from Siberia via New York.

DR. E. R. BUCKLEY, consulting mining geologist, died very suddenly from pneumonia at his home in Chicago, January 18, and his wife died of the same cause, January 24. Dr. Buckley was for seven years State Geologist of Missouri and director of the State Bureau of Geology and Mines at Rolla, Mo.

CHARLES GILBERT WHEELER, assistant state geologist of Missouri from 1859 to 1861, professor of chemistry in the old University of Chicago from 1868 to 1889, since then consulting mining geologist and mining expert, died on January 30 in Chicago, at the age of seventy-five years.

DR. GEORGE JARVIS BRUSH, Professor Emeritus of Geology in the Sheffield Scientific School of Yale University, and Director of the School from 1872 to 1898, eminent for his contributions to the science of mineralogy, died on February 6, aged eighty years.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

DR. J. B. WOODWORTH has been promoted to an associate professorship of geology at Harvard University.

SIDNEY L. GALPIN, instructor in mineralogy, Cornell University, has been appointed assistant state geologist of Georgia, to succeed Otto Veatch, who accepts a position with the U. S. Bureau of Soils.

MR. A. C. VEATCH, having returned from a year's examinations and explorations in the Trinidad and Venezuela oil fields, and having resigned from the U. S. Geological Survey, where he was geologist and chairman of the land classification board, will practise as a consulting geologist. His address is 3415 Ashley Terrace, Washington, D. C. Mr. Veatch was in the California oil fields early in February.

MR. GEORGE BORUP, who was in charge of the third supporting party of Admiral Peary in his last polar expedition, has been appointed assistant curator in the department of geology and invertebrate paleontology of the American Museum of Natural History.

THE Academy of Natural Sciences of Philadelphia has awarded the Hayden Medal in gold for distinguished work in geology to Professor John C. Branner, of Leland Stanford Jr. University.

MAJOR CLARENCE EDWARD DUTTON, U. S. A., retired, distinguished for his services in the Civil War and later in the ordnance corps of the army and eminent for his contributions on volcanoes and earthquakes, died on January 4 at his home in Englewood, N. J., aged seventy years.